NREL
Transforming ENERGY

WIND ENERGY RESEARCH & DEVELOPMENT
Technology Innovation

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Technology Innovation

Disseminating wind energy information, developing wind energy tools and resources, and researching community impact issues to increase public acceptance of wind energy deployment and build connections with wind energy stakeholders.

Next-Generation Wind Turbines

Conducting early-stage research on promising rotor configurations, turbine architectures, and manufacturing approaches

Floating Offshore Wind Systems

Focusing on controls, reliability, modeling and simulation, validation and certification—and more

Plant-Level Control

Reducing the loads on wind turbine components while capturing more wind energy and converting it into electricity

Drivetrain Technology, Operations, and Maintenance

Developing advanced drivetrains and prognostic technologies to increase performance, torque density, and reliability—and to reduce operations and maintenance costs

Next-Gen Wind Turbines

- NREL analyzes innovative wind turbine subsystems and configurations that show promise for transformational changes in our ability to deploy wind energy.
- Our team evaluates these novel approaches through numerical modeling and simulation in advance of hardware development, reducing the risk of pursuing potentially game-changing technology.

Areas of Expertise

- Aerodynamics, aeroelasticity, and structural dynamics
- Computational fluid dynamics
- High-performance computing.

Current Projects

Big Adaptive Rotor Project

CHALLENGE

Very large rotors have significant cost and maintenance advantages, but the logistics of moving, erecting, and maintaining supersized turbines require innovative design approaches.

APPROACH

NREL researchers analyzed 17 novel concepts with the potential to reduce the levelized cost of energy for 100-meter (and above) land-based wind turbines. The Big Adaptive Rotor Project team evaluated the benefits and costs of each option to determine the six most viable concepts for future research and development.

IMPACT

Larger, advanced adaptive rotor systems can produce electricity at extremely low cost and high-capacity factors, opening new opportunities for regional deployment.

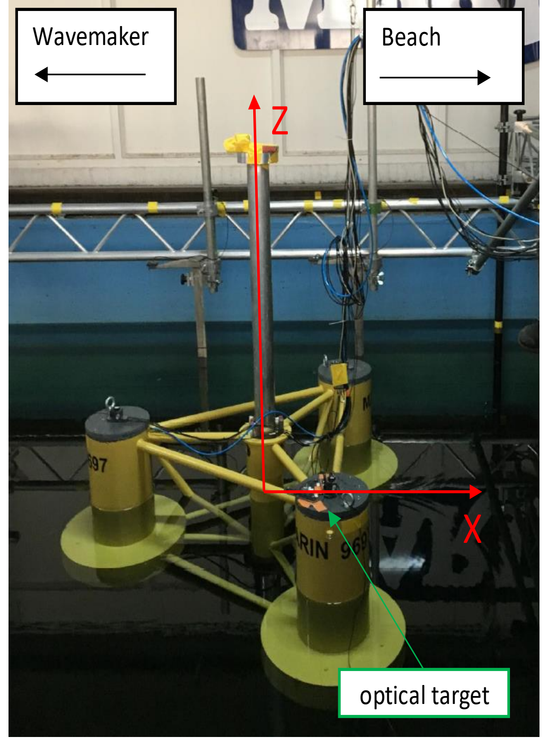
NEXT-GEN WIND TURBINES

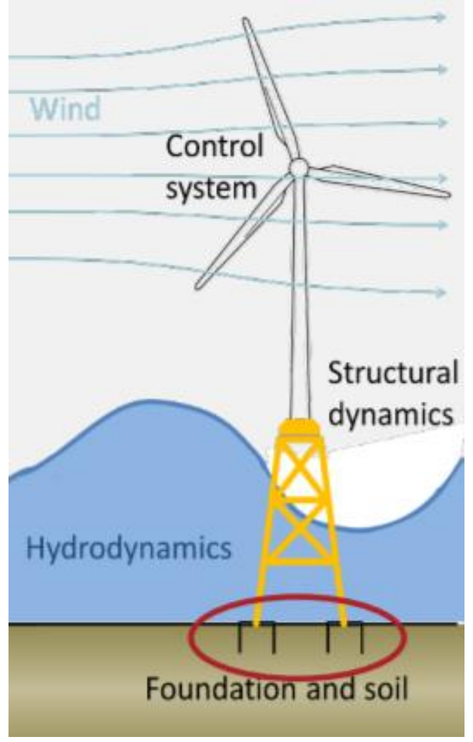
Floating Offshore Wind Systems

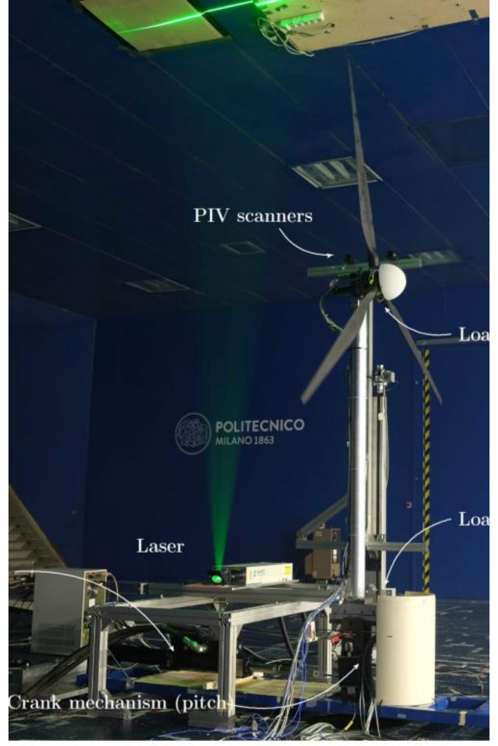
- Building wind plants in water depths greater than 60 meters offers tremendous opportunity for wind deployment, including almost the entire west coast of the United States
- The deep offshore opportunity requires floating solutions that stretch the capabilities for system design and optimization
- NREL's offshore wind turbine research capabilities focus on the long-term needs of the industry, including developing innovative controls at the turbine and plant levels, advancing modeling and simulation capabilities to assess and optimize novel designs, and supporting standards development.

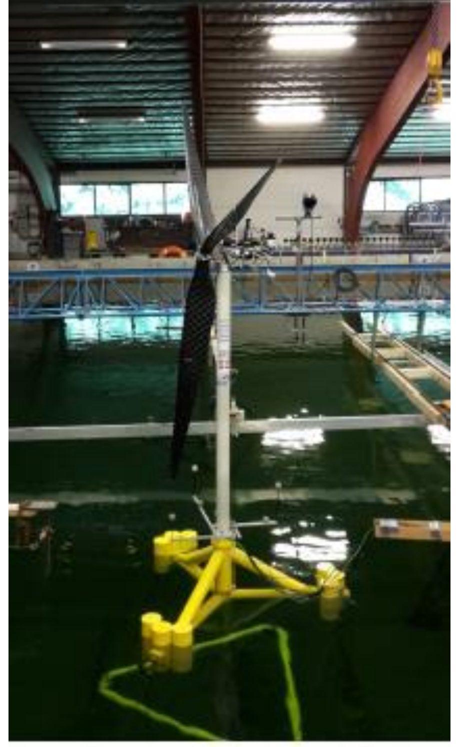
Areas of Expertise

- Analysis and design of innovative substructures and moorings
- Advanced modeling capabilities, validation, and optimization
- Aerodynamics, aeroelasticity; hydrodynamics; mooring systems; structural dynamics and marine architecture
- Computational fluid dynamics.









Current Projects

IEA Wind Collaborative Code Validation (OC6) Project

CHALLENGE

To ensure the reliability and cost-effectiveness of offshore wind systems, offshore design codes that consider the coupling between aerodynamic and hydrodynamic loading need to be validated for a variety of designs and conditions.

APPROACH

NREL is leading an international collaborative effort to validate the most critical phenomena in predicting offshore wind system loads. A three-way validation and verification process compares solutions from the new coupled engineering-level models to high-fidelity models and experimental data.

IMPACT

Validation will increase the level of trust and acceptance in offshore wind design tools, which directly affects the perceived risk in a project, impacting design methodology and bankability. Validated modeling tools can then be used to design next-generation offshore wind systems that will have lower costs.

FLOATING OFFSHORE WIND SYSTEMS

Current Projects

Advancing Modeling Capabilities to Design the Floating Wind Systems of the Future

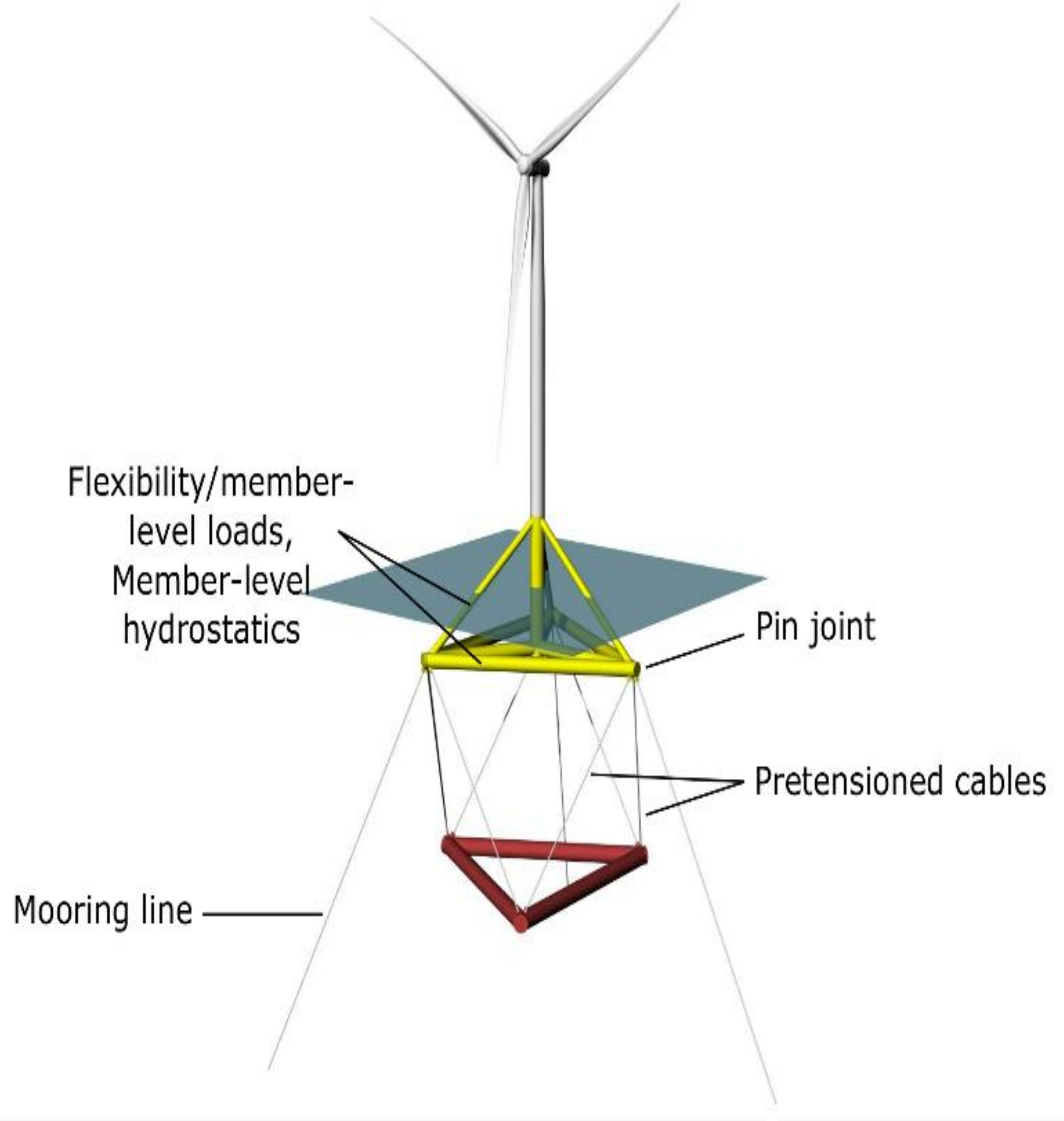
FLOATING OFFSHORE WIND SYSTEMS

CHALLENGE

Innovative floating designs are sought to provide significant cost-reduction pathways that do not rely on overly robust offshore oil and gas production solutions. To find these innovative solutions, modeling capabilities are needed that can accurately represent their novel design components—to assess their feasibility and impact.

APPROACH

Identify the innovative design approaches being envisioned to drive down floating wind costs, and advance modeling capabilities to assess the viability of these technology advancements. Develop tools that assess trade-offs in design approach to identify optimal innovation pathways.



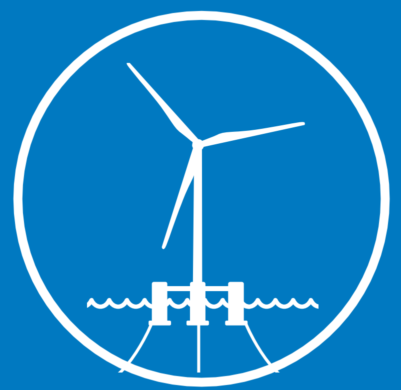
IMPACT

Validated modeling capabilities will be available to the public—capabilities that enable the examination of innovative design approaches and will lower the cost of floating offshore wind systems.

Current Projects

ARPA-E ATLANTIS projects:

- WEIS
- USFLOWT
- FOCAL



FLOATING OFFSHORE WIND SYSTEMS

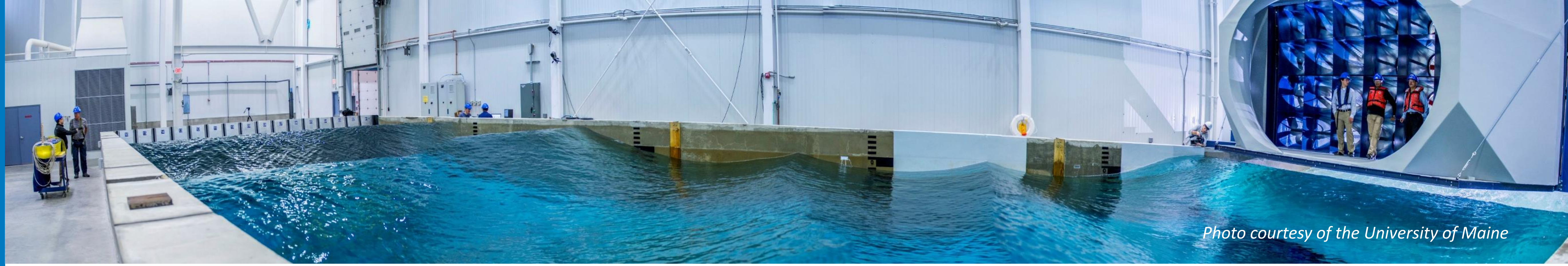


Photo courtesy of the University of Maine

CHALLENGE

Current floating wind designs are large and bulky to withstand the harsh environmental conditions offshore. But control methods can be used to modify their dynamic response, which can help to decrease the support structure requirements, thus enabling a "light-weighting" of the design.

APPROACH

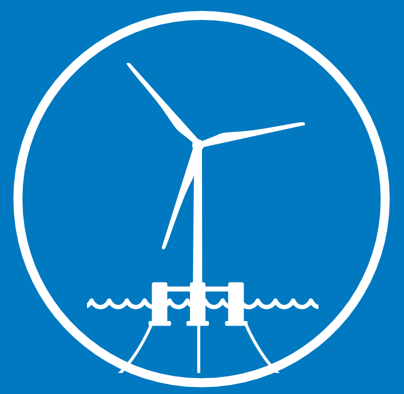
Develop and implement control codesign (CCD) capabilities in floating wind design and optimization tools (WEIS project) to integrate controls features with the structural and aerodynamic/hydrodynamic design choices to achieve a comprehensively optimized solution. Then, apply these capabilities to develop an innovative CCD-derived floating wind design (USFLOWT project). To ensure these new capabilities and design approaches can be effective for real-world systems, develop an experimental validation data set focused on demonstrating the influence of controls on floating wind dynamic behavior (FOCAL project).

IMPACT

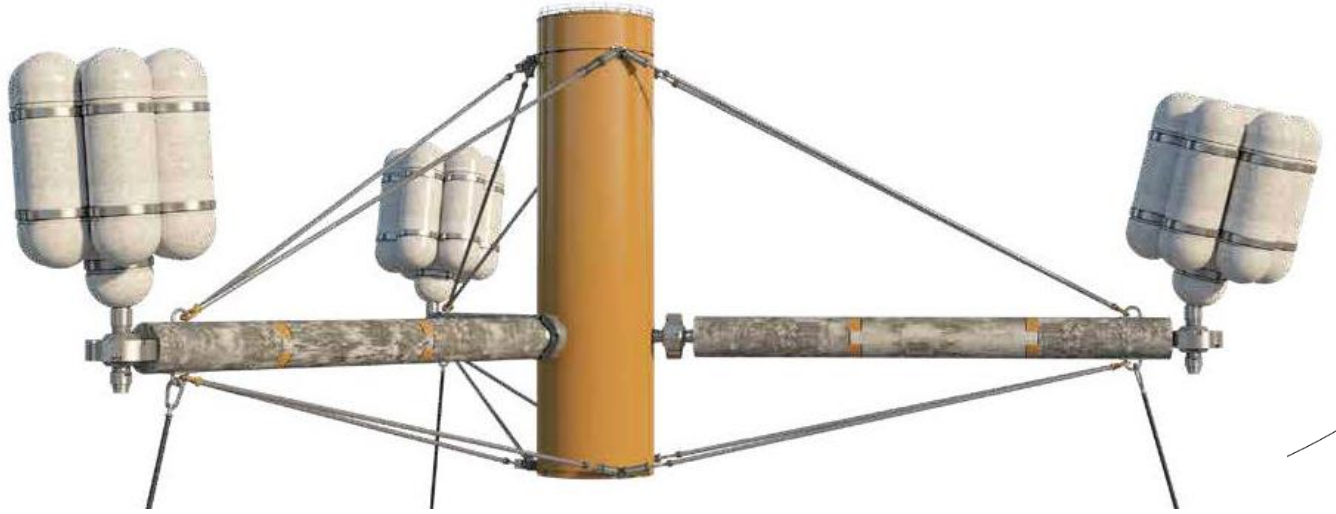
Optimized systems based on CCD will reduce the cost of energy for floating offshore wind systems to levels competitive with or below current fixed-bottom designs.

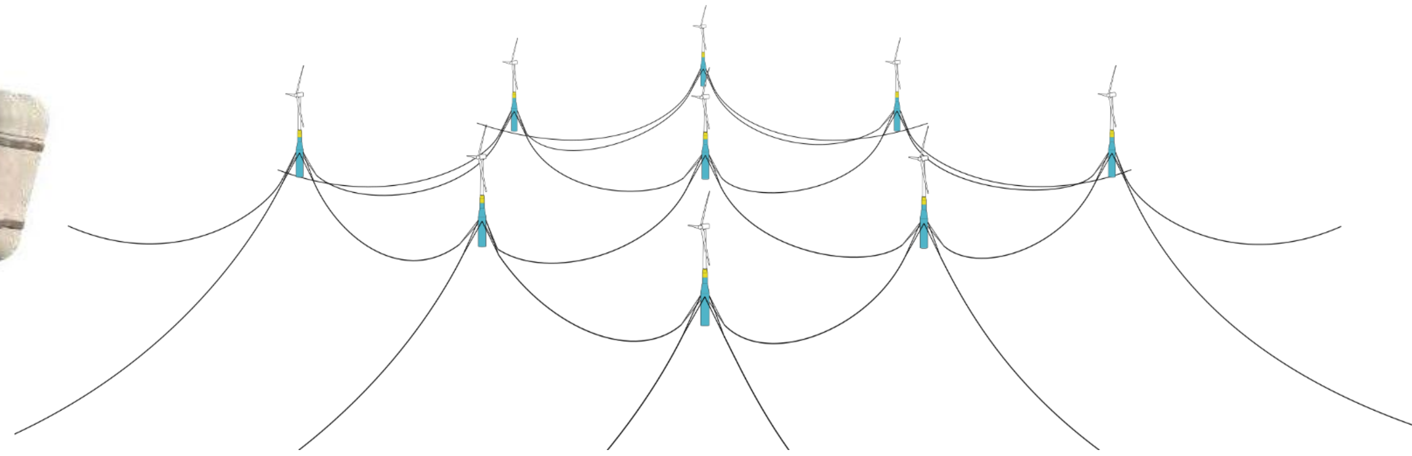
Current Projects

Design of Innovative Substructures and Mooring Systems



FLOATING OFFSHORE WIND SYSTEMS





CHALLENGE

Floating wind plants in deep water need more efficient designs to be cost competitive.

APPROACH

Develop and examine innovative floating wind plant design solutions that will lower costs, including streamlined substructures that rely on novel components and advanced control methods. At the plant level, develop shared mooring and anchor systems, minimizing a floating wind plant's anchor count and mooring line lengths.

IMPACT

NREL's design work will demonstrate the feasibility and impact of innovative design solutions, which will accelerate industry adoption.

Plant-Level Control

- Advanced wind turbine controls can enable annual energy production and reduce losses by more than 20%.
- NREL is researching new control methodologies, such as wake steering and consensus control, for both land-based and offshore wind plants.

Areas of Expertise

- Wake control design and analysis
- Wind plant optimization
- Turbine modeling and simulation
- High-performance computing.

Current Projects

Wind Power Plant Control Campaign at Peetz Wind Energy Facility

CHALLENGE

Evaluate the performance of wind power plant control at a commercial wind facility.

APPROACH

NREL designed a wind power plant control strategy based on wake steering to implement at the Peetz Wind Energy Facility in collaboration with its owner, NextEra Energy. The field campaign, which was the first of its kind, ran successfully for several years.

IMPACTS

- Results demonstrated how existing facilities can achieve annual energy production and reduce losses by more than 20%, depending on plant size and design, by steering individual turbine wakes away from downstream turbines.
- For a 300-megawatt wind power plant, the expected outcome could generate an additional $1 million per year.
- This effort represents a successful implementation of wake steering at a large-scale facility.

PLANT-LEVEL CONTROL

Drivetrain Technology, Operations, and Maintenance

- NREL develops and verifies advanced drivetrain concepts and innovative bearing, gearbox, and generator technologies.

- We lead the Drivetrain Reliability Collaborative to increase drivetrain reliability and turbine availability through improved designs and prognostic technology, thereby reducing operations and maintenance costs.

Areas of Expertise

- Drivetrain innovation
- Drivetrain modeling, analysis, and validation
- Prognostics and health management
- Reliability, operations, and maintenance.

Current Projects

Uptower Investigation of Main and High-Speed-Shaft Bearing Reliability

DRIVETRAIN TECHNOLOGY, OPERATIONS, AND MAINTENANCE

CHALLENGE

Premature drivetrain failures often lead to higher-than-expected operations and maintenance costs for wind facilities.

APPROACH

The NREL team tailored instrumentation within the gearbox to understand the causes of bearing axial cracking and, on the main bearing, investigated the causes of progressive wear. Both conditions can lead to premature drivetrain failure. The impacts of atmospheric conditions, transient events, and grid events created by the controllable grid interface on bearing conditions were investigated.

IMPACT

Bearing loads, sliding, and motion models were developed and validated that can be integrated as new life-rating metrics, allowing these failure modes to be accounted for in the design process.

Current Projects

Reliability Assessment and Prognosis for Gearbox Bearings

DRIVETRAIN TECHNOLOGY, OPERATIONS, AND MAINTENANCE

CHALLENGE

Minimal understanding of component damage and its progression hinders operations and maintenance optimization and reduces turbine availability.

APPROACH

The NREL team developed a general reliability assessment and prognosis methodology, using gearbox bearing axial cracking as an example failure mode, from physics models, wind plant operations data, and failure records. The probability of failure for individual bearings in each turbine in the wind plant was assessed.

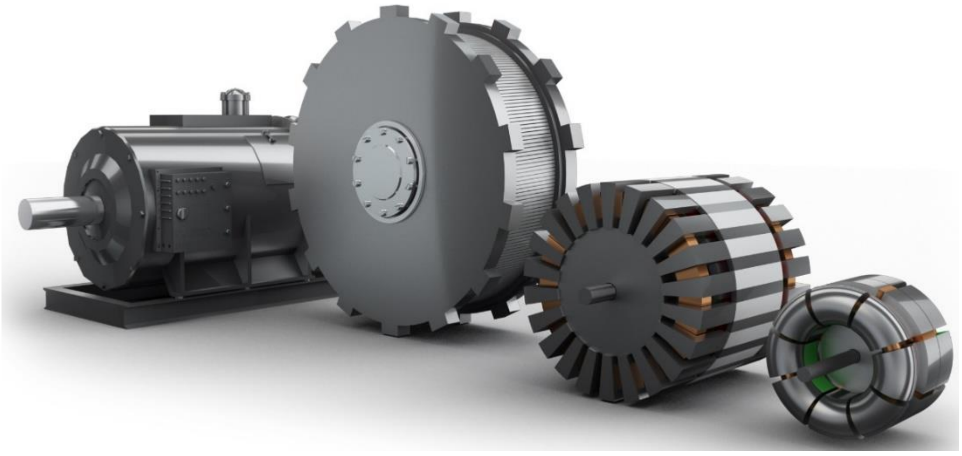
IMPACT

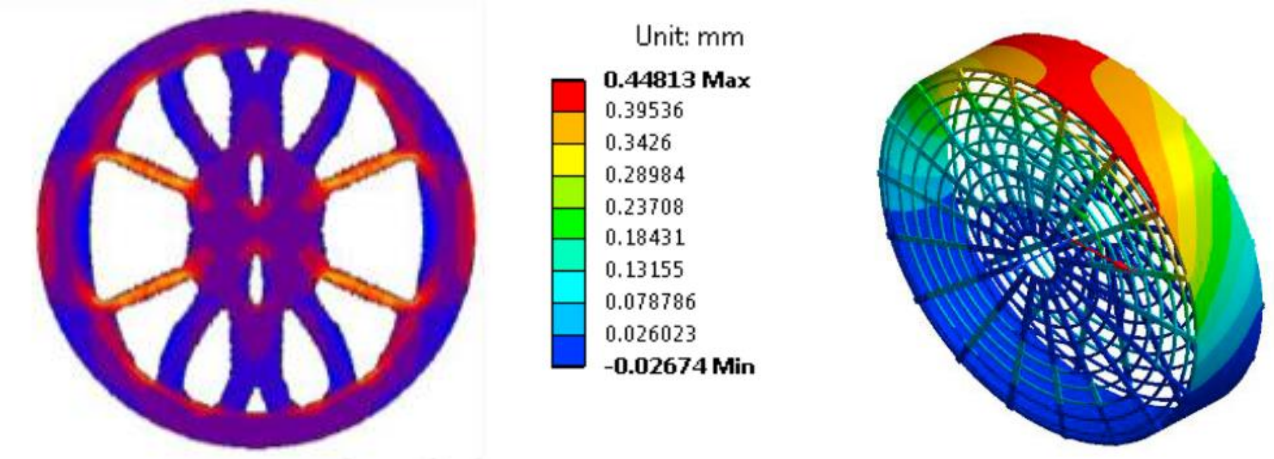
The methodology can be used to predict the reliability of individual gearbox bearings in each turbine based on the drivetrain and bearing design, the model of each failure mode, and the operational characteristics of the turbine.

Current Projects

MADE3D: Manufacturing and Additive Design of Electric Machines Enabled by 3D Printing

DRIVETRAIN TECHNOLOGY, OPERATIONS, AND MAINTENANCE





CHALLENGE

Traditional approaches to designing and manufacturing direct-drive electric generators result in prohibitively expensive and heavy powertrains that are no longer cost effective for large wind turbines.

APPROACH

NREL researchers and their partners are leading the design, fabrication, and verification of the world's first fully additively manufactured direct-drive electric generator. Using new topology-optimization software, the team is exploring opportunities for weight reduction and improvements in torque densities using high-performance, low-cost materials and multimaterial printing technologies.

IMPACT

The MADE3D effort is developing the topology-optimization software to produce electric machines with high torque density and identifying risks, opportunities, and challenges with the integration of multimaterial, 3D-printing processes.

Accomplishments & Impacts

NREL experts pioneered many of the capabilities that have taken wind energy to new heights. Our computer modeling and experimental capabilities, as well as our deep staff expertise, are guiding wind technologies from initial concepts to deployment, including:

- Investigating innovative wind turbine systems and configurations able to transform wind energy.
- Creating design tools and optimization software to enable both floating offshore and manufacturable/transportable land-based installations.
- Researching new plant-level control operations for both land-based and offshore wind turbines, which, if fully successful, will have the potential to raise annual energy production and reduce losses by more than 20%. For a 300-megawatt wind power plant, the expected outcome could generate an additional $1 million per year.
- Reducing operations and maintenance costs by increasing turbine reliability and plant availability with enhanced designs and prognostic technology.