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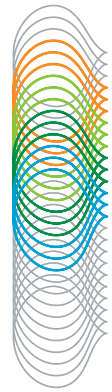
The Spectrum of
Clean Energy Innovation



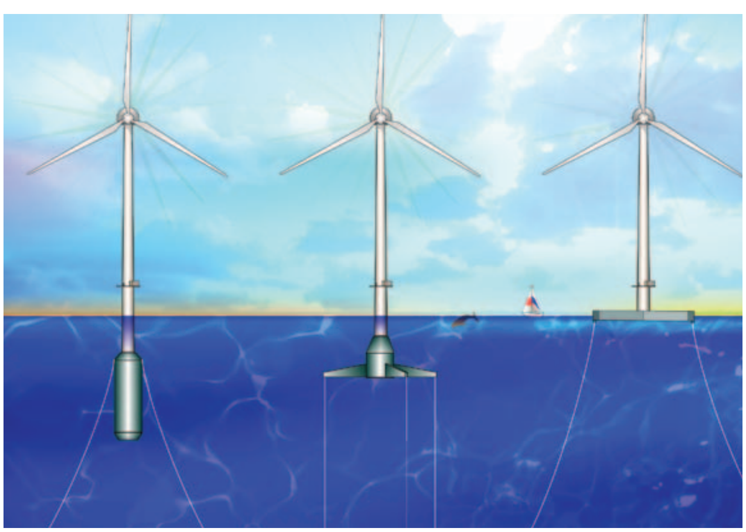
NREL Computer Models Integrate Wind Turbines with Floating Platforms

Far off the shores of energy-hungry coastal cities, powerful winds blow over the open ocean, where the water is too deep for today's seabed-mounted offshore wind turbines. For the United States to tap into these vast offshore wind energy resources, wind turbines must be mounted on floating platforms to be cost effective. Researchers at the National Renewable Energy Laboratory (NREL) are supporting that development with computer models that allow detailed analyses of such floating wind turbines.

Coupling wind turbines and floating platforms requires complex computer models. Land-based wind turbines are designed and analyzed using simulation tools, called computer-aided engineering (CAE) design tools, that are capable of predicting a design's dynamic response to wind conditions and calculating the extreme and fatigue loads the system can endure. These CAE tools incorporate models for wind inflow, aerodynamics, control-system behaviors, and structural-dynamic effects. The models are then used to simulate the conditions and stresses that a wind turbine experiences.

Currently, most offshore wind turbines are installed in shallow water on bottom-mounted substructures. These substructures are either monopiles—gravity-based foundations that are used in water to a depth of about 30 meters (roughly 100 feet)—or space-frames, such as tripods and lattice frames, that are used in water depths of up to 50 meters, or about 165 feet.

In recent years, a number of CAE tools for land-based wind turbines have been expanded to include the additional dynamics pertinent to these bottom-mounted offshore support



Three concepts for floating wind turbines are the "spar-buoy" (left), which is stabilized by a heavy ballast; the "tension-leg" platform (center), which is stabilized by its mooring lines; and the barge (right), which is stabilized by its buoyancy. Illustration by Al Hicks, NREL

Through deep technical expertise and an unmatched breadth of capabilities, NREL leads an integrated approach across the spectrum of renewable energy innovation. From scientific discovery to accelerating market deployment, NREL works in partnership with private industry to drive the transformation of our nation's energy systems.

This case study illustrates NREL's analysis and decision-support capabilities, which enhance innovation across the spectrum. This example highlights analysis contributions in Market-Relevant Research through Testing and Validation.

NREL
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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

structures, including models for incident waves, sea currents, and the foundation dynamics of the support structure. However, none of these tools accounted for mooring-system dynamics and the hydrodynamic effects that occur under conditions such as wave radiation (the propagation of waves traveling outward from the platform resulting from platform motion) and wave diffraction (the augmentation that occurs when incident waves encounter a platform).

For floating wind turbines, the CAE tools must simultaneously model the effects of waves, sea currents, and platform and mooring response. NREL's complex simulation tool models the dynamic response of offshore floating wind turbines, incorporating important characteristics and physical phenomena, and is capable of analyzing the complexity of proposed offshore floating wind turbine systems and the variety of their configurations.

Numerous floating platform configurations may be used with offshore wind turbines. Current proposals for floating wind turbine systems are based on a variety of mooring systems, tanks, and ballast options used with platforms developed for the offshore oil and gas industry. These may be classified in terms of how they achieve stability when the platform pitches and rolls in the water.

Three primary concepts are tension leg platforms, spar buoys, and barges, as shown in the front-page illustration. These platforms provide stability primarily through a combination of their mooring systems and provisions for the buoyancy and ballast of the platform. Hybrid concepts that use features from more than one classification, such as semi-submersibles, are also possible.

Considerable analysis is required to develop cost-effective floating wind turbine designs that are capable of penetrating the competitive energy marketplace. NREL's CAE tool, referred to as FAST, helps quantify and analyze the coupled architecture, providing designers with a tool to analyze the most cost-effective design.

The new offshore floating wind turbine models were the result of more than two decades of work by NREL and others. The models combine the computational methodologies of NREL's land-based wind turbine models with the hydrodynamic theory and computer programs developed for offshore oil and gas industries by a variety of entities, including the Massachusetts Institute of Technology.

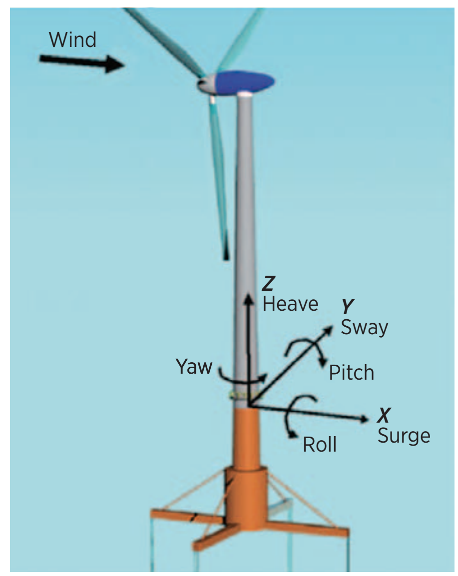
NREL researchers verified FAST using model-to-model comparisons and have performed conceptual design and analysis studies for land-based and sea-based systems. These studies enable them to quantify the impact of the dynamic coupling between the wind turbine and floating platform under combined wind and wave conditions. In addition, FAST was verified through participation in the Offshore Code Comparison Collaboration, which was led by NREL and operated under the auspices of the International Energy Agency.

The NREL-developed CAE tools have become the industry standard for analysis and development and are used by thousands of users, including all major U.S.- based (and many international) wind turbine and floating platform designers, manufacturers, consultants, and researchers. The tools are now being applied to many promising floating wind turbine concepts and designs.

Simulations will help to resolve the fundamental design trade-offs of the various concepts for floating wind turbines, quantifying how the choice of platform configuration affects the wind turbines' performance and the total system's cost. Further testing is underway, and it's too early to say which concept or system design is the most cost- and design-effective. But the NREL models will serve as a critical tool for evaluating the designs as this nascent industry moves from concept to commercial reality.

Floating Platforms Add Six New Modes of Motion

Innovating beyond previous code limitations, NREL researchers have upgraded their land-based simulation tool to create a design tool that models the dynamic response of offshore floating wind turbines. Part of this upgrade was the introduction of six degrees of freedom to characterize the motion of the support platform. The design tool now simulates all six modes of motion in the support platform, including translational movement in three dimensions—surge, sway, and heave—along with rotational roll, pitch, and yaw. The complete coupled model is distinct from previous models used in the offshore wind turbine industry.



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