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Innovative Offshore Vertical-Axis Wind Turbine Rotor Project

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Abstract

A research project has recently begun to explore the viability of vertical axis wind turbines (VAWT) for future U.S. offshore installations, especially in resource-rich, deep-water locations (1). VAWTs may offer large reductions in cost across multiple categories, including operations and maintenance (O&M), support structure, installation, and electrical infrastructure costs. The cost-reduction opportunities follow from three fundamental characteristics of the VAWT: lower turbine center of gravity, reduced machine complexity, and the opportunity for scaling the machine to very large sizes (10–20 MW).

Objectives

The over-arching objective of this project is to demonstrate the superiority of the VAWT architecture for very large-scale deployment in the offshore environment. The most critical barrier to offshore wind, high COE, is specifically targeted with the overall goal of demonstrating a 20% reduction in COE through application of VAWT rotor technology. This goal will be achieved by:

- Development of innovative VAWT rotor designs that enable reliable, cost-effective, and easily manufactured rotors for deep-water offshore machines at the 10–20 MW scale
- Demonstration of the potential for greater than 20% reduction in COE for a deep-water, floating VAWT system compared to current shallow-water HAWT systems
- Development of manufacturing techniques, certification test methods, and a commercialization plan for offshore VAWT rotors in order to accelerate deployment
- Wind tunnel and combined wind-wave tank testing of a proof-of-concept, subscale, deep-water floating offshore WTG employing a VAWT rotor.

Methods

The anticipated distribution of lifetime costs for offshore wind turbines are shown in Fig. 1. The support structure, operations and maintenance (O&M), and other balance of station costs (BOS) account for 60% of the total. VAWTs have the potential to reduce

- Support structure costs by lowering the turbine center of gravity
- O&M costs by positioning the drivetrain near the surface and reducing the number of components
- BOS costs by allowing for scale-up to larger machine sizes

Furthermore, VAWTs are inherently insensitive to wind velocity and direction shear, which allows scale up to large sizes without performance losses. However, experience with VAWTs has shown that there are significant technological challenges to overcome. A list of the primary opportunities and challenges is listed below and shown in Fig. 2.

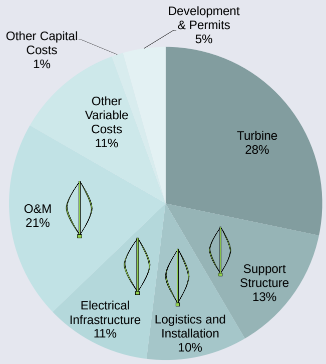

Fig. 1: Estimated Life-Cycle Cost Breakdown for an Offshore Wind Project (2), and Areas that VAWTs Improve.

VAWT Opportunities

- Insensitivity to wind direction
- Reduced mechanical complexity
- Lower center of gravity
- Drivetrain at/near the surface level
- Lower gravitational fatigue loads
- Improved stability in floating configuration
- Potentially higher aerodynamic efficiency (3,4)

VAWT Challenges

- Longer total blade length per swept area
- Cyclic loading on the drivetrain
- Lower aerodynamic efficiency for previous designs (5)
- Structural resonances during operation
- Lack of aerodynamic braking system

Thus, the tasks in the project will be aimed at the development of a design that will best exploit the opportunities that VAWTs offer while mitigating the challenges. A 2-year design tool and concept development phase will be followed by a 3-year design and build phase, culminating in the testing of a sub-scale prototype in a combined wind/wave basin.

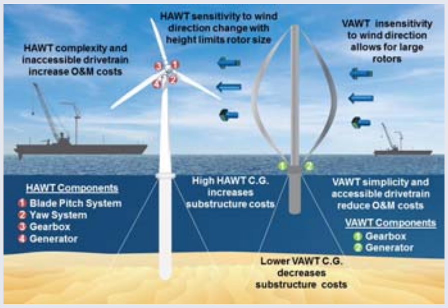

Fig. 2: Comparison of HAWT and VAWT Machines for Offshore Deployment

The project team consists of academic and industry partners, with consultation from similar E.U. efforts (6). The specific role of each partner is as follows:

- Sandia National Laboratories: Project leadership, development of rotor aeroelastic tool, and system design.
- University of Maine: Floating VAWT floating platform dynamics code and subscale prototype wind/wave basin test.
- Iowa State University: Development of manufacturing techniques for offshore VAWT blades and sub-scale wind tunnel testing.
- TPI Composites: Manufacture of subscale blade hardware for proof-of-concept demonstration and development of a commercialization plan.
- TU-Delft: Aero-elastic design and optimization tool development and modeling.

Results

While, the project is currently at the beginning stages, work has been completed on a few tasks including a very preliminary look at offshore VAWT economics, initial design tool and reference model development, and concept selection.

Cost Modeling: Fig. 3 summarizes the results from a preliminary cost and energy-production analysis. All costs are given in 2010 U.S. dollars and draw upon previous work (7). The total estimated potential reduction in COE from the baseline is 28%. The most important COE reduction categories are the increased annual energy production, and reduced O&M, support structure, and BOS costs. These reductions more than offset the increase in blade costs due to the longer VAWT blades. The deep-water deployment in a larger wind resource plays an important role, accounting for 32% of the COE reduction due to increased energy capture. However, calculations were also performed for the HAWT baseline in the deep-water wind resource, and COE reduction for the VAWT concept relative to the revised baseline is still 21%. These COE estimates give confidence that the deep-water VAWT concept has the potential to achieve the project's goal of at least 20% COE reduction.

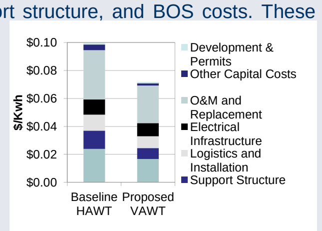

Fig. 3: Potential COE Reduction for Offshore VAWTs

Code and Reference Model Development: Work has begun on an aero-hydro-servo-elastic code to model the operation of a floating offshore VAWT. The code uses a finite element model of the rotor and will be coupled to existing inflow, aerodynamic, and platform hydrodynamics codes. Also, and the construction of a 5MW reference model is underway. The model will be based on a scale up of the SNL 34-m VAWT (8), using modern wind blade concepts (9) (see Fig. 5). Finally, initial concepts based on spar-buoy, Darrieus and V-shaped configurations with have been chosen (see Fig. 6)

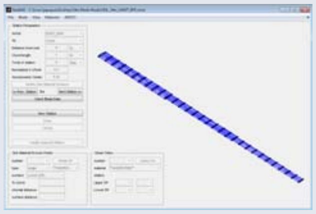

Fig. 5: NuMAD Model of 5WM Reference Darrieus VAWT Blade

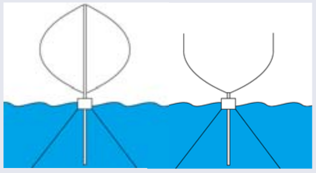

Fig. 6: Initial Floating VAWT Concepts

Conclusions

HAWTs have emerged as the predominant technology for land-based wind over the past 15 years primarily due to advantages in rotor costs at the 1–5 MW machine scale. These machines have experienced nearly an order of magnitude decrease in cost of energy (COE) over the last three decades and have achieved cost parity with other generation sources in recent years. However, in the context of offshore wind economics, especially for deepwater applications at the 10–20 MW scale, the VAWT architecture is a potentially transformational technology—something that may be necessary for large-scale offshore wind development.

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