ACTIVE STABILIZATION OF A FLOATING WIND TURBINE PLATFORM

THE MEANS AND MOTIVES OF CAPE WIND OPPOSITION

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Mechanical Engineering

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Fall 2021

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Socio-Technical Problem

Offshore wind power has grown considerably over the past decade, and with recent goals from President Biden to install 30 GW by 2030, the market is expected to continue its expansion. In the United States alone, there are currently two operating offshore wind farms with 15 other projects along the Northeast in the development pipeline (United States Department of Energy [DOE], 2021). Recently, however, motivation for a new type of floating offshore wind turbine (FOWT) has risen due to the space and surplus of wind resources in deeper waters. This type of technology is a potential driver to lowering the cost of energy, as fixed foundations in deep water are too expensive, and it would provide for cheaper installation and transportation (Williams, 2020).

Although there are currently a number of pilot FOWTs installed around the world, many challenges still exist in deploying them at an industrial scale. One such problem is the stabilization of the floating turbine's platform; instability of the platform can lead to efficiency problems and fatigue damage to the blades (Yang et al., 2019). Currently, designs address this problem with passive systems, which are less effective, or active systems, which are too slow to respond (Salic et al., 2019). To address the technical challenges of these current stabilization measures, my team and I will propose an active cable tightening system that instantaneously and effectively damps the effects of sea waves on the turbine platform.

However, it is important to also consider the social and political factors that will play a role in the success of this design. These additional factors include public opinion, government regulations, fossil fuel interests, and the media portrayal of clean energy technologies. In order to further examine these factors and the heterogeneous network of FOWT technologies, I will also be examining the failed case of Cape Wind, an offshore wind project that was set to be the first

US offshore wind farm but failed due to heavy opposition and economic burdens (Janik, 2021). By analyzing this case, I hope to provide a greater understanding of the roles of the stakeholder and the influence that the government and public opinion will have on the success of FOWTs. Moreover, negligence of these social and political factors may lead to the termination of future wind projects that could have otherwise contributed to the nation's green energy profile.

Therefore, the growth and success of the offshore wind market is socio-technical in nature and, as such, requires proposals that address both technical and social aspects. Using mechatronics and active control, I will confront instability problems of FOWTs by modeling an active stabilization system that acts quickly and effectively. Next, I will apply Active-Network Theory to an analysis of Cape Wind and the competing interests of social and government stakeholder groups to determine the human and non-human factors that influence the success of offshore wind projects.

Technical Problem

Currently, there are 11 floating offshore projects installed around the world, however none of them are at a utility scale, and none of them are in the U.S. One of the primary reasons for this lack of development is the cost: floating platforms have much higher installation costs and are accompanied by lengthy underwater transmission lines. In fact, the cost to produce the same amount of energy with a floating farm is on average three times higher than that of a fixed farm (Speht, 2021). To counteract these high costs, FOWTs must be made as efficient as possible, and power efficiency is highly dependent on platform stability. If the platform cannot effectively damp wind and wave conditions, the pitch control of the blades can become disturbed leading to lower power generation and risk of damage (Yang et al., 2019). Pilot projects have confronted this problem using two techniques: passive stability, which achieves stability through the basic geometry of the platform, and active stability, which senses the waves and balances the platform by providing a counter-acting force. Of the passive types, there are three main designs which can be seen in Figure 1. The spar-buoy takes advantage of a lower center of gravity to achieve stability, the semi-submersible distributes its weight into three large columns for maximum buoyancy, and the tension-leg platform locks itself to the seabed with high-tension anchor ropes (Salic et al., 2019).

Figure 1. From left to right: Spar-buoy, Semi-submersible, Tension-leg platform.

While these designs are technically feasible and have been shown to limit some impact of the wind and waves, each of them comes with its own flaws and limitations. For one, the spar-buoy has very little depth independence and 5 MW turbines using this technology may only be placed in waters deeper than 50 meters. This applies further limitations on the site selection process, which is already very restricted due to government regulations and public interest. Next, the semi-submersible platform has a much higher wave sensitivity due to a greater surface area; this makes stabilizing the platform difficult especially when there are extreme weather conditions. Finally, the drawbacks of the tension-leg platform design include high anchoring costs and complex on-site installation. To maintain stability with a tension-leg platform, its anchor mooring system must never go slack even in deep waters, providing a rather resource-heavy design challenge. Although there are some active stability approaches that attempt to solve these problems, they are slow to respond to wave conditions and often require major modifications to the turbine itself (Yang et al., 2019). If these problems can be offset with a new design, the power efficiency of FOWTs can increase which would minimize the economic burden of floating wind projects.

The goal of this technical project is to design an additional active stabilization method that can effectively and instantaneously damp the effect of wave conditions on a semi-submersible platform. The design will utilize gyroscopic sensors embedded on a model FOWT to sense the tilt of the platform, and it will subsequently adjust the tension in the mooring cables to reset the platform to a horizontal position. Using motors to tighten the anchors, the design will be able to react more quickly than current passive stabilization measures.

My team and I will first need to analyze the buoyant and applied forces on the structure to ensure that the cable tightening system does not cause failure of components or lead to the platform sinking. Next, we will model how the platform reacts to different frequencies and magnitudes of waves using a large water tank to simulate the ocean. Finally, we need to develop a mathematical model for a control system that takes platform tilt as an input and gives the necessary amount of tightening for each anchor rope as an output. We will then code the control system into an Arduino microcontroller which will communicate with the gyroscope and each motor to effectively stabilize the turbine platform. The gyroscopic data that we collect will allow us to determine the effectiveness of the design and compare it with the previous passive model.

STS Problem

In August of 2001, energy entrepreneur Jim Gordon first announced his plans to build 130 turbines off the coast of Cape Cod as part of a proposed $500 million clean energy project. It was set to be the United States' first offshore wind farm and would power over 200,000 homes in Cape Cod, likely promoting a trend of future offshore projects along the East Coast. Early designs placed the turbines just under 5 miles off the coast in the middle of Nantucket Sound, the body of water beloved by many locals for its diverse marine wildlife and beautiful views (United States Department of the Interior, 2010). On the other hand, Nantucket Sound also provided some of the greatest wind resources in the entire US and a very enticing location for a highly profitable offshore wind project (Schwartz et al., 2010). Soon after the proposal was announced, controversy erupted and opposition groups formed, resulting in a fierce battle between developers, homeowners, environmentalists, and politicians. In 2010, Gordon was issued a federal permit to start construction, but with the ferocity of opposition, few banks believed in Cape Wind and economic barriers began to pile up. In the end, not a single turbine was ever installed, and Gordon was forced to surrender his lease in 2017 after 16 years and $100 million of investments (Seelye, 2017).

Although the failure of Cape Wind is often described by economic setbacks and an inability to acquire sufficient funding, this reason fails to consider the dozens of actors and stakeholders that funded opposition and exploited the courts to delay and bleed the project of its time and money. Some examples of such stakeholders include the Wampanoag tribe, which considered the waters to be of great cultural importance, or the Alliance to Protect Nantucket Sound, which was founded and funded by the rich donors of Cape Cod (Janik, 2021). If we continue to assume that only the economic shortcomings of the project were responsible for its failure, we will not understand the influence that other actors may have, and future well-funded clean energy projects may be terminated for similar reasons.

I argue that high project costs and poor funding in conjunction with local and federal governments, wealthy opposition, fossil fuel interests, ill-defined permitting processes, and litigation led to the termination of Cape Wind. These actors were collectively responsible because they led to constant delays in the development process as well as confusion and polarity within the public. Actor-Network Theory (ANT) is an analytical framework that describes human and non-human actors as a system of relationships where each actor is both composed of and included in another actor-network. Additionally, ANT attempts to explain the actions of network builders, like Jim Gordon, and the reasons for the success or failure of a network. For a network to be successful, all actors must be connected and understood, and no actor is privileged over others. Furthermore, translation is the process by which networks are formed and maintained (Cressman, 2009). Drawing on ANT, I plan to map out the process by which the network of these groups was created and the reasons for which the network dissolved into such controversy and failure. To support my claim, I will analyze video interviews of key players from both sides, media advertisements, environmental impact statements, and arguments by members of Congress, which provide insight into the motivations and strategies of opposing actors.

Conclusion

The final product of the technical project will be a proof of concept model of an active stabilization system for a FOWT that actively adjusts the tension of the anchoring cables to provide stability from incoming waves. The STS research paper will inspect primary sources from the failed Cape Wind project to better understand the influences of competing social and political groups. This analysis will be structured using ANT to identify the root causes of network dissolution and the role of both human and non-human actors as it relates to the development of offshore wind farms. The findings in both the technical and STS research project will contribute to the transition to clean energy and the growth of the offshore wind market by targeting technologies that could lower the cost of energy and social factors that stand in the way of the acceleration of offshore wind development.

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