Prospectus

Development of Floating Wind Turbine Base for Increased Stability and Decreased Costs
(Technical Topic)

How Floating Wind Turbines Can Increase Public Acceptance and Implementation of Renewable Energy
(STS Topic)

By

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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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Introduction

A floating wind turbine is an offshore wind turbine fixed to a floating structure which is then connected to the sea floor using mooring lines. The floating nature of these wind turbines allows them to generate energy in water depths of over 160 feet where fixed-foundation turbines cannot be built due to high costs and engineering difficulties. The majority of offshore real-estate is at or beyond this depth as well as more reliable winds. Because of this, floating wind turbines make it possible to significantly expand the area for offshore wind farm implementation and increase wind generated electricity. Thus, our capstone project focuses on designing a floating wind turbine base that will increase stability and decrease costs, which would make the implementation of floating wind turbines more feasible. This would ultimately lead to an increase in renewable energy, creating a greener and more sustainable earth.

While my capstone project targets the issues of cost and stability to promote the implementation of floating wind turbines, the STS thesis illustrates the increased public acceptance of renewables introduced by this technology. Wind turbines have seen much resistance from society in the past because of their looming presence, disruptive noise, visual pollution, and high costs. Due to public resistance, wind farms are developed in remote areas that have limited space. The limited application of wind turbines poses a significant environmental threat, since every day with less renewable energy generation means more fossil fuel production. My STS research investigates how implementing low cost floating wind turbines can alter the negative public perception of renewable energy, therefore leading to a greater production of clean energy.

Technical Topic

The objective of this project is to create a design that increases the utility of wind turbines. To achieve this goal our group has targeted floating wind turbines, which can significantly increase the utilization of wind energy. According to Walter Musial, a leading expert in offshore wind for the National Renewable Energy Laboratory, 80 percent of the world's offshore waters suitable for wind turbines near major population centers are deep (News, n.d.). This means that our wind resources are being severely underutilized without the access to deep waters that floating wind turbines provide.

Although this relatively new technology is known to be more expensive than well-established fixed-bottom offshore turbines, it has already been proven in some small arenas. Hywind Scotland is a $152 million project that was launched in 2017 which consists of 5 floating wind turbines positioned 18 miles off of Peterhead, Scotland. This project has an electricity generating capacity of 30 MW, or enough to power 20,000 homes (*Will Floating Turbines Usher in a New Wave of Offshore Wind? - Yale E360*, n.d.). The success of these floating wind turbines was proven by the very high capacity factor of over 50% compared to the U.S. fleetwide average of 35% (*Wind Energy Factsheet | Center for Sustainable Systems*, n.d.). Capacity factor is the actual power output of a wind turbine divided by the maximum power output of that wind turbine and can be affected by how sustained the winds are, which is clearly superior for the floating turbines (LuvSide, n.d.). However, the operating and maintenance costs of these are almost double that of fixed-bottom offshore wind turbines (Gourvenec, n.d.).

The three major types of floating substructures for floating wind turbines are spar-buoy, barge, and tension-leg platform (TLP), which are depicted in figure 1. Any platform that is stable during float-out such as a barge shape avoids the costs of special purpose ships needed to transport bases such as spars and tension-leg platforms with buoyancy tanks. In addition, buoyancy tanks in the shape of a barge are more economic to manufacture compared to spar-buoys and tension-leg platforms due to established fabrication techniques (Butterfield, n.d.). Although the barge offers the most economic option, it is also the least stable because it has greater exposure to waves on the water plane.

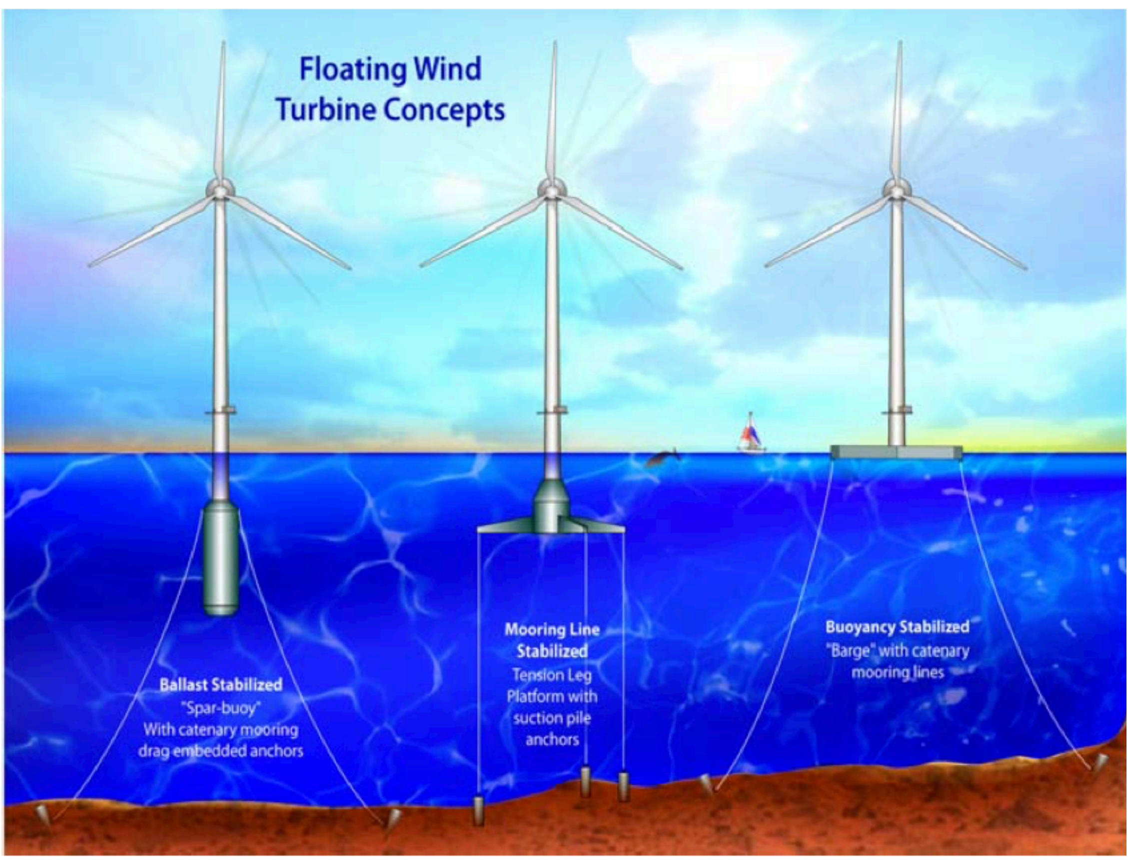

Figure 1: Typical Floating Platform Static Stability Concepts (Butterfield, n.d.)

Under the guidance of Michael Momot, Ph.D., Cydnie Golson, Emily Fedroff, Ahmed Abdelnabi, Kelly Boenisch, and I will develop a new floating wind turbine base in the form of a barge with higher levels of stability and lower costs. We are developing this to make it more feasible to implement floating wind turbines in deeper waters where turbines can harness more reliable winds, which would therefore produce more electricity. The novel base design employs passive stabilization, which allows for lower production costs and maintenance requirements while improving performance. This will make the typically unstable barge design more resilient while maintaining low costs. With passive stabilization, there is no active control and corrective actions are not required ("CONSIDERATION UPON FIXED ANTI - ROLLING PASSIVE SYSTEMS," 2016). Our specific design shown in figure 2 is a semi-submersible floating platform with chambers which fill and drain at a rate dictated by the size of the small holes dividing the chambers. The decreased cost and maintenance that this design provides will ultimately lead to the adoption of floating wind turbines at a larger and more realistic scale.

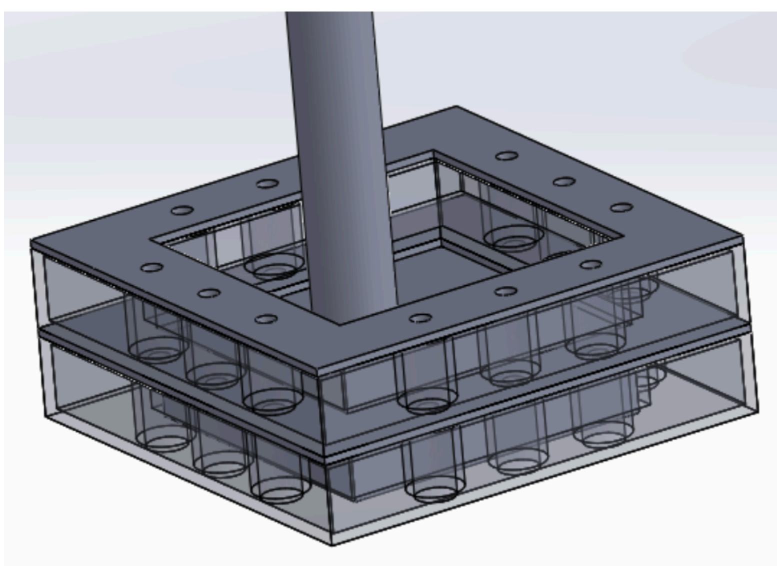

Figure 2: Capstone base design using SolidWorks

The design will first be analyzed by conducting a bode plot analysis on the base, in which the optimal frequency of the base will be determined. Then, using Torricelli's principle, the drain rate of the tank holes will be determined to provide the best stability possible in order to cancel out wave frequencies. Once this is determined, a 3-D printed prototype will be built to test in a large basin of water in which waves will be simulated and the frequency and amplitude of the base will be measured using software called Vernier Physics Pro. Once this data is collected, it will be determined if this proposed design provides higher levels of stability at a lower cost compared to existing floating wind turbine base designs.

STS Topic

Wind is a source of power in which we have only scratched the surface, with 7.3% of the U.S.'s electricity coming from traditional wind turbines (*Electricity in the U.S. - U.S. Energy Information Administration (EIA)*, n.d.). This staggeringly low number is due to the limited area suitable for wind turbines without public resistance both on U.S. soil and in offshore locations. With almost two-thirds of America's electricity generation coming from fossil fuels, the current situation cannot be supported longer without permanent environmental damage, if it hasn't occurred already. In order to hopefully reverse the ecological impacts that fossil fuels have had on the Earth, renewables must be embraced by society and implemented as soon as possible. Goals have been set, such as Virginia's goal to reach 100 percent carbon-free electricity by 2045 (*Virginia Mandates 100% Clean Power by 2045*, n.d.). A main step to make this goal attainable is to alter the current public perception of renewables, especially wind energy, and create social acceptance of wind energy through the implementation of floating wind turbines.

The main issues influencing the social acceptance of wind energy are technical characteristics of the project, environmental impacts, societal impacts, economic impacts, contextual factors, and individual characteristics. After examining these key issues, the most dominant factors are the size and visibility of the project from residential areas, the impacts on the environment such as greenhouse gas emissions and potential impacts on birds and bats, the adverse effects on quality of human life such as the cognitive effects of noise pollution, and the cost of the project (Leiren et al., 2020).

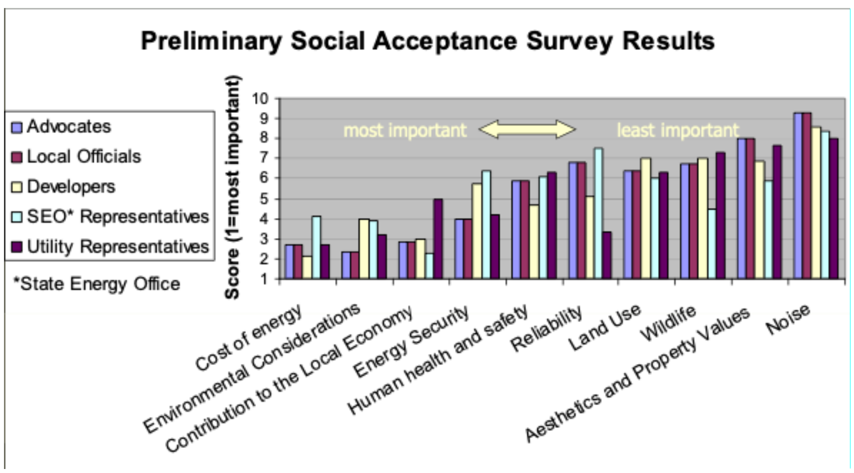

Figure 3: NREL Study(Tegen & Lantz, n.d.).

Figure 3 depicts a study done by the National Renewable Energy Laboratory which shows the importance of factors in the social acceptance of wind energy according to different stakeholders. Factors on the left were seen as the most important by all stakeholders and factors on the right were seen as least important by all parties (Tegen & Lantz, n.d.).

Although the present fossil fuel industry in the United States creates many of these issues including high costs, environmental impacts, and potential health effects caused by greenhouse gasses, it is not as concerning because people have become accustomed to an electricity system that is essentially "invisible" to consumers. This is owed to centralized infrastructure typically sited far from population centers. The physical removal of power stations from most populated areas also removes them from the minds of the people. However, wind turbines cannot do this since they require a highly dispersed and visible distribution, usually in attractive and unspoiled areas (Rand & Hoen, 2017). The visual impacts from wind turbines have even been sighted as property-rights infringement in some cases because people are so accustomed to the less visible fossil fuel industry.

On the other hand, floating wind turbines can be implemented at distances of 18 miles as shown by the Hywind Scotland project, while the human eye can rarely see more than 12 miles, even on a clear day (Team, 2012). This eliminates most factors that create resistance against wind energy, such as sight and sound. The remaining factors, such as environment and economic impact are also reduced. This is because less birds and wildlife are found at these far distances compared to the coast and the highly reliable winds at these depths of the ocean guarantee energy production that will produce a return on investment faster than any other wind turbine. However, floating wind turbines are much more expensive than their traditional counterparts. For example, one floating turbine built for Hywind Scotland had a project cost of $30 million, while the average wind turbine costs around $5 million ("How Much Does a Wind Turbine Cost?," n.d.). Although this seems like a massive imbalance, the constant energy produced by the reliable winds encountered by a floating wind turbine make up for some of this added expense compared to the varied winds that a traditional turbine has. In addition, these expenses can be reduced through the economic passive stabilization design that we have been developing. Because the main negative public sentiment caused by wind turbines is removed by floating wind turbines, I believe that they are a likely solution to the lack of social acceptance with traditional turbines and will promote the generation of renewable energy.

I plan to analyze the effectiveness of the passively stabilized semi-submersible floating wind turbine base that my team has designed. In doing so, we will determine if a more economically viable floating wind turbine will prove successful and therefore allow for the expansion of the floating wind turbine industry. Empirical evidence sources will include reports of the costs of different fixed-bottom and floating wind turbine projects and the amount of electricity these projects produce. From this information, different returns on investment can be calculated, and I hope to find data that will show floating wind turbines gaining a competitive return on investment. The stakeholders and actants involved include engineers, the Department of Energy, maintenance and construction crew, government, and the general public. Floating wind turbines are shown to be more successful at generating electricity through more steadfast winds as well as lower interference with the public, and I hope that my research will lead to a positive change in the public perception of wind energy.

Next Steps

- Calculate dimensions of CAD model based on a scale of a true sized wind turbine.
- Create 3-D printed prototype of naturally pressurized floating wind turbine base.
- Perform bode plot analysis to determine optimal frequency of base.
- Develop a reliable method to test the prototype in a basin of water with limited variables between tests.
- Use Vernier Physics Pro to find the amplitude and frequency of the base.
- Collect data on the performance of the base in a simulation and compare to the performance of existing floating base designs on stability.
- Perform a cost analysis of the proposed base design and gather cost information on existing designs to compare.
- Stay up to date with any new designs of floating wind turbines or new projects in the engineering world.
- Incorporate new data gathered into a thesis in the beginning of next semester.

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