Active Control of Wind Turbine Blades to Increase Efficiency
(Technical Paper)

Analyzing Public Opinion on Wind Energy in the United States
(STS Paper)

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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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Prospectus

Introduction:

The effects of climate change are not only becoming increasingly apparent, but research continues to conclude that these effects may soon become irreversible (Hotz & Puko, 2021). With this knowledge comes a growing pressure on global powers, be they nations or corporations, to make changes and address the issue. The most pressed of these changes is the reduction of greenhouse gas emissions, gases whose release into the atmosphere prevents heat escaping from Earth (Denchak, 2019). Significant quantities of greenhouse gas emissions come from electricity production. As such, the development of effective, clean energy generation technology is paramount. For this paper, clean energy sources will be considered those sources which produce minimal greenhouse gases. The most common clean energy sources are solar power, nuclear, hydroelectric, and wind. Of these clean energy sources, the largest producer is distinctly nuclear, although of the strictly renewable energy sources the largest is wind power (EIA, 2021). For that reason, the following technical research and STS research paper will focus on wind energy. Wind energy has several notable weaknesses that must be addressed as its role in national energy production grows. These weaknesses will be divided into technical issues and sociopolitical concerns. On the technical side, wind turbines need to produce more reliable energy and do so quieter, safer, and with reduced ecological impact (Office of Energy Efficiency and Renewable Energy, 2021). To address this, the technical project will be based on improving wind turbine power production by investigating whether mechanisms that change the blade shape are effective at improving low wind speed energy production. The STS research paper will be dedicated to analysis of the sociopolitical angle. The emphasis will be on the complicated relationships involved in the public opinion of wind energy in the United States, both as an independent technology but also in the context of being an alternative to fossil fuels.

Improving Wind Turbine Energy Production via Blade Expansion Mechanism:

While pitch control is industry standard, the manipulation of blade shape has not seen widespread uptake in the wind turbine industry. The overarching goal of the technical project is to design a mechanism that actively changes the shape of the blade to improve overall turbine efficiency for varying wind speeds. Current methods of raising turbine efficiency include pitch control, larger blades, and changing blade shape. The equation for turbine power generation is $P = ½ C_P ρV^3A$, where P is power, C_P is the coefficient of performance, ρ is the density of the air, V is the velocity of the wind, and A is the swept area of the blade (Sarkar & Behera, 2012). Only swept area and the coefficient of performance are modifiable, so any designs must involve improving these values. The trend has been to create larger turbines, but this causes concerns with transportation, construction, and lifespan. A less common approach is to actively change the blade shape to improve C_P at different wind speeds, which will be explored in this project.

More specifically, this project aims to increase the efficiency and reliability of the GE 2.78MW-120m turbine across wind speeds from 3 m/s to 20.5 m/s. As shown in Figure 1, these wind speeds represent the designed minimum and maximum operating wind speeds for the turbine, referred to as the cut-in and cut-out speeds (Bauer & Matysik, 2021). At these speeds, the turbine stops spinning entirely.

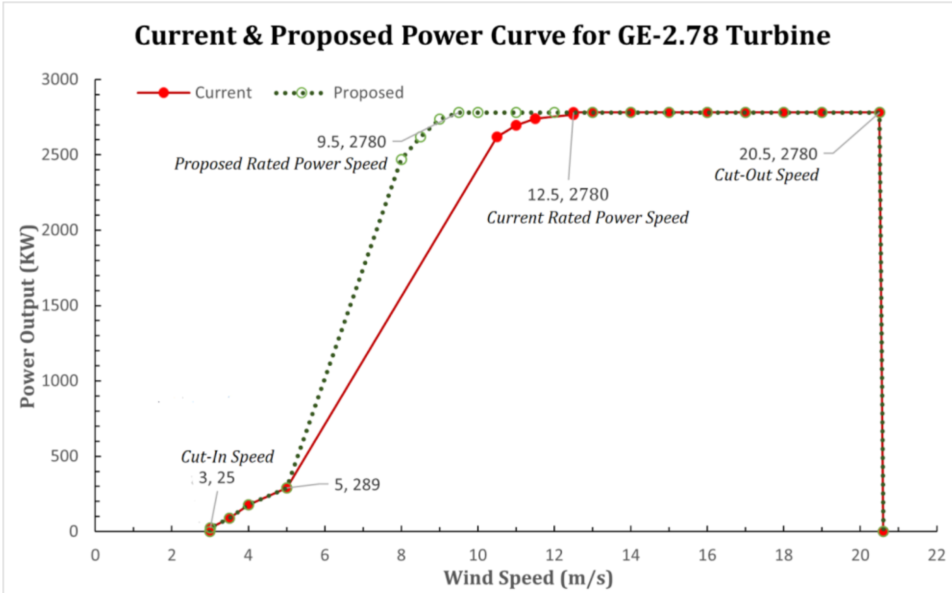

Figure 1: Current and Proposed Power Curve for GE-2.78 Turbine. This plot was created by the project team using data from Bauer & Matysik, 2021

From Figure 1, it is important to note the cut-in speed is particularly invariable; there must be a minimum energy present in the wind for a turbine to collect and transform into electricity. However, the wind speed at which the turbine reaches its rated power can be reduced by improving the aerodynamic efficiency of the turbine. Shown in Figure 1, the team's goal is to decrease the rated power wind speed from 12.5 m/s to 9.5 m/s. Preliminary analysis of the graph shows that this would result in an annual 6% increase in electrical power generation.

For the last few decades, wind turbine manufacturers have used pitch control, which is changing the angle of attack (AoA) a turbine blade makes with the wind to alter the aerodynamic coefficients of lift and drag. These variations in the AoA, lift, and drag coefficients determine the rated power wind speed and allow the turbines to spin at a constant rotational speed during its rated power phase (Muljadi & Butterfield, 1999). A constant rotational speed is essential to maintaining a reliable connection with the national electrical grid, by harmonizing the frequency phase of the electricity the turbine generates and the phase of electricity needed for distribution.

While pitch control systems are effective, they are complicated, with a typical system consisting of over 4,000 subcomponents and many sensitive electronic modules. According to a 2011 report, 23% of all wind turbine downtime was directly related to pitch control system failures. Additionally, the study found that pitch control systems marked the highest failure rate of any turbine component, at 21%. Remarkably, a pitch control system only has a system reliability of 5,700 hours, or a little over half a year, while a typical turbine lifetime is expected to be well over 20 years (Wilkinson et al., 2011).

There is a clear demand for an alternative active control system that captures the aerodynamic efficiency improvements of pitch control, but performs reliably over the course of a turbine's life. During the screening and scoring process, the team considered manufacturing costs, system simplicity, performance improvements, and reliability and decided on an extendable and retractable flap system on the trailing edge of the turbine blades, analogous to flaps on the trailing edges of airplane wings.

3D Computer Aided-Design (CAD) models of the proposed active control system will be created using SOLIDWORKS 3D design and simulation software and validated using its Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) tools. Furthermore, the team will 3D print and prototype the proposed mechanism as a scaled down turbine, which will be verified using wind tunnel testing. Finally, the team will complete a failure mode & effects analysis (FMEA) and levelized cost of energy (LCoE) analysis to evaluate the importance of the solution to the turbine manufacturing industry.

Analyzing Public Opinion on Wind Energy in the United States:

Reduction of greenhouse gas emissions is key in slowing and hopefully reversing the process of climate change. All in all, general electricity production accounts for 25% of greenhouse gas emissions which are the main drivers of global climate change (EPA, 2021). According to the Energy Information Administration (2021), fossil fuel energy, derived from coal, petroleum, and natural gas, makes up 79% of energy consumed in the United States. On the other hand, 12% of US energy consumption consists of clean energy, which produces little to no greenhouse gas emissions. About 3% of all energy consumed in the US is sourced from wind energy farms, and this number has been slowly increasing over the last several decades, and will likely continue to do so (EIA, 2021). Transitioning away from fossil fuel energy to clean energy could play a large role in mitigating climate change, and as such, accelerating this transition would be beneficial. This transition will naturally involve many groups, each of which share complicated relationships and interdependencies.

Of particular interest are the sociotechnical relationships between the public and its perception of clean energy, as the public in the US has a crucial role in the growth of clean energy. Within these relationships are cultural, economic, political, and technological issues. Culturally, the issues of land usage, visual and audio pollution, and depreciated property value are pressing (Berkely Labs, 2019). Free land can be used for many purposes, be it agricultural industrial, or reserved for nature. Unfortunately, wind farms must be located in regions with strong wind conditions to improve output and close to population centers to reduce transmission losses. The consequence of this is limited wind farm site options because land usage and wind farm requirements must be aligned. Politically, it is notable that the two major US parties have differing stances on fossil fuel usage and how to transition away from them (Gustafson et al., 2020). Related is the effect of where the public sources their information, as this affects what biases the information will carry. Expansion of wind energy (and clean energy more broadly) will have to address the elimination of fossil fuel jobs as well. Although, renewables currently employ more individuals than the coal industry in the US and is actively expanding (Shenette, 2018). Finally, perceptions of the actual technology behind wind energy are key in public opinion, but part of this rests on the actual efficacy of the technology. This aspect is best addressed by improving the technology, which is a constant and ongoing process. Ultimately, the public elects officials who support or oppose clean energy, the public decides whether land can be devoted to clean energy generation, and the public purchases and uses the electricity. As such, a careful understanding of what affects public support of clean energy is essential, as they dictate the final outcomes at each stage.

In order to adequately analyze these relationships, the involved groups, and their impact on wind energy development, the Social Construction of Technology (SCOT) framework will be used. First developed by Trevor Pinch and Wiebe Bijker (1984), this framework has four key components: interpretive flexibility, relevant social groups, closure and stabilization, and wider context. Interpretive flexibility refers to identifying the differences in interpretation of a technology between the social groups involved. Related to this, the relevant social groups in the development of a technology need to be identified as well. The next component, closure and stabilization, refers to how interpretive differences between social groups are solved, and eventually all groups settle on a common interpretation. Finally, wider context is the addressal of the greater significance of a technological development. Each of these will be considered in the context of wind energy, but focusing on public support of wind energy. One major benefit of SCOT includes its firm structure from which to base an analysis. This structure consists of the four key components mentioned, as well as the rejection of technological determinism, which is the belief that technology exerts the single largest influence on the shaping of society (Smith, 1994). SCOT focuses on the specific groups involved in the development of a technology, emphasizing that technological development is an interactive and collaborative process. While SCOT addresses the human agents of technological development, it can underestimate the power dissonance between social groups. As Klein and Kleinman (2002) note in their criticism of SCOT, "closure and consensus around a final design can only be explained with reference to the power relationships between groups" (p. 39). Careful consideration of the relative power of social groups must therefore be taken. Further, it is possible that over the course of research, important social groups are neglected entirely. For this reason, careful and thorough research is essential. By being aware of these analytical weaknesses, the benefits of SCOT can be maintained and provide great insight into public opinion on wind power.

Research Question and Methods

The final goal of this research paper is to analyze what sociotechnical relationships inform public opinion on wind energy, and how they affect the development and expansion of wind energy in the United States. By researching associations between clean energy and political ideology, generation, geographic region, and demographics, a baseline can be drawn. To do this, surveys performed by large, national, organizations like the Pew Research Center will be analyzed. From here, investigating the reasons behind the data trends can inform what actual groups are at play, and how they influence public support. This will be done primarily via documentary research methods by finding articles and papers online and on UVA's Virgo system. Search keywords and phrases such as, "renewable energy," "wind energy," "wind turbines," "public opinion," "advantages and disadvantages," "fossil fuels," "climate change," “power grid,” “electricity production,” and more will be used. To better understand energy systems in general, research on the power grid, economics of electricity production and consumption, and the reliability and efficiency of clean energy and fossil fuel energy will be essential. Given the many social groups involved in the future of wind power, all with their own respective goals for wind power, the SCOT analytical framework will be ideal. A network analysis of these social groups will be insightful as well, allowing for an understanding of how the key social groups interact, which are strongest, most influential, and excluded.

Conclusion:

To reiterate, the final goal of the technical project is to design, prototype, and test an active mechanical system to expand blade width in an effort to improve turbine effiency. Assuming the technical project is a success, a new way to improve turbine blade efficiency will be demonstrated. If the technical project’s results are less than expected, valuable new data regarding such blade expansion mechanisms will exist and can inform future designs and experiments. This information will contribute to the technological development of wind turbine technology, and will in turn further the process of advancing renewable energy in general. With the completion of the STS research paper, a better understanding of wind energy public opinion and the factors involved will be established. Through knowledge of these relationships, the transition to renewable energy could be accelerated and smoothed, preventing further climate change while protecting public livelihoods. In effect, these projects together can provide valuable information to protect both short term and long-term quality of life as the threat of climate changes looms.

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