Undergraduate Thesis Prospectus

Optimizing Wind Turbine Blades for Low Wind Speeds

(technical research project in Mechanical Engineering)

The Struggle over Wind Farm Development on Tribal Lands in North America

(sociotechnical research project)

by

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November 1, 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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General Research Problem

How can wind energy use be broadened?

As the world begins to realize the dire consequences of global warming, countries across the globe face mounting pressure to implement renewables with haste. Under the 2015 Paris Agreement, nearly all the world's 195 countries committed to shifting towards net-zero emissions and limiting the global temperature increase to under 2 degrees Celsius this century (United Nations, 2021). Many have embraced wind energy to meet these goals. "Over the past decade, wind turbine use has increased more than 25 percent per year" (National Geographic, 2021). However, further expansion of wind developments is limited by both the technological advancement and social implications of their implementation. Thus, these projects aim to explore ways of improving turbine efficiency and understand some of the social impasses that face wind energy expansion.

Optimizing Wind Turbine Blades for Low Wind Speeds

How can the overall efficiency of wind turbines be increased for a larger range of wind speeds?

This capstone project will be led by a team of six students under the supervision of Professor Momot in the mechanical engineering department.

The overarching goal of this project is to design a mechanism that actively changes the shape of a wind turbine blade to improve the overall turbine efficiency under 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 $P = \frac{1}{2} C_P \rho V^3 A$, 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 the swept area and the coefficient of performance are modifiable, so any designs must involve improving these values. The trend has been to create larger and larger turbines, but this causes concerns with transporting parts of the turbine to the construction site, constructing the turbine itself, and lifespan. A less common approach is to actively change the blade shape to improve C_P, which will be explored in this project.

More specifically, this project aims to increase the efficiency and reliability of the GE 2.75MW-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). Outside of this range of speeds, the turbine stops spinning entirely.

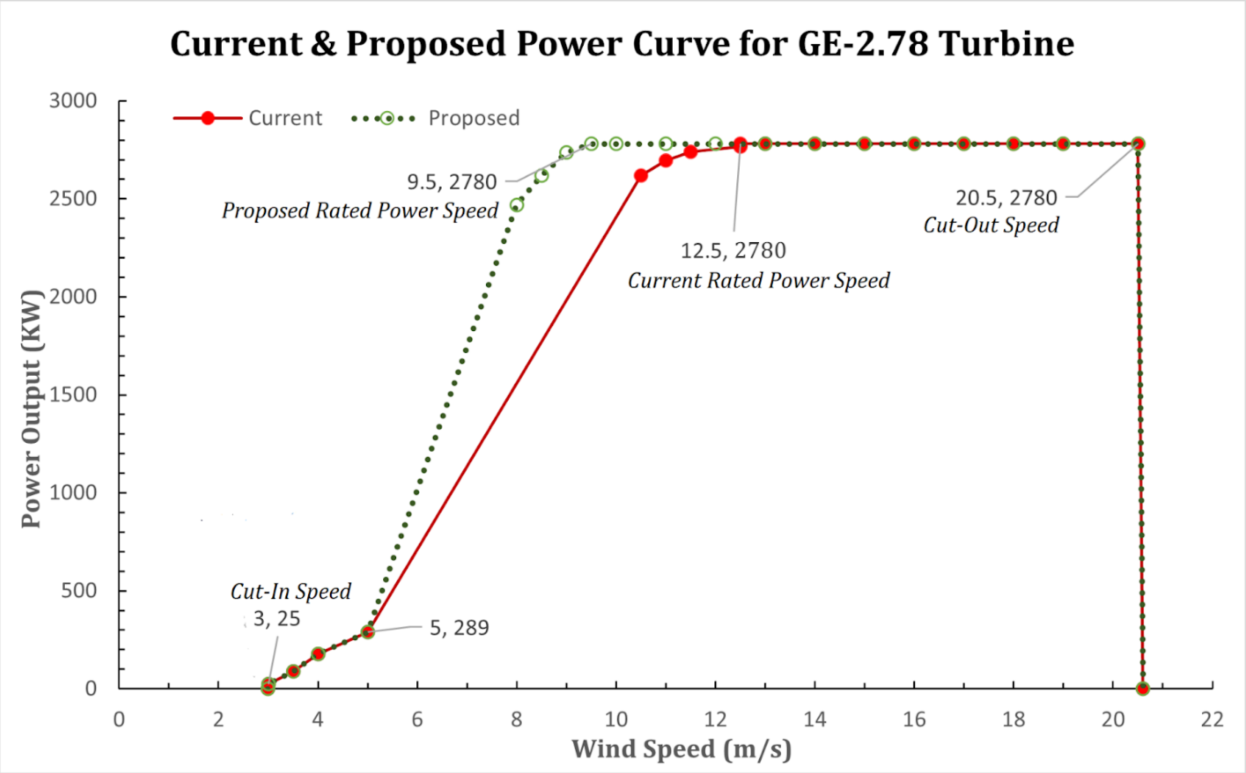

Figure 1: Current and Proposed Power Curve for GE-2.78 Turbine (Bauer, 2021)

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, changing the angle of attack a turbine blade makes with the wind, to alter the aerodynamic coefficients of lift and drag. These variations in angle of attack, 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 paramount 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 (Wilkinson et al., 2011). 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).

Clearly, there is a demand for an alternative active control system that captures the aerodynamic efficiency improvements of pitch control but performs reliably over the course of the life of the turbine. 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 CAD models of the proposed active control system will be created using SOLIDWORKS software and validated using ANSYS FEA and CFD tools. Furthermore, the team will 3D print and prototype the proposed mechanism into a scaled down turbine, which will be verified using wind tunnel testing. Finally, the team will complete a failure mode and effects analysis (FMEA) and levelized cost of energy (LCoE) analysis to evaluate the importance of the solution to the turbine manufacturing industry.

The Struggle over Wind Farm Development on Tribal Lands in North America

In North America, how do indigenous peoples seek to influence wind farm developments on tribal lands?

Wind farm siting can be a complicated process. Neighbors to wind farms often complain of the visual aesthetics, noise, and flickering shadows caused by spinning blades. (U.S. Department of Energy, n.d.) To avoid opposition, many wind power developers look for sparsely populated areas to establish new wind farms. Yet in tribal areas, such projects may be opposed as unwelcome intrusions on ancestral lands. While some tribal members typically welcome wind farms, others oppose them, especially near cultural sites. So how have indigenous peoples sought to either protect tribal lands from wind farm projects, or ensure that such developments are consistent with tribal values?

Researchers have investigated instances of wind developments troubling indigenous peoples before. Rubiano (2021) found that the Colombian government is currently constructing wind turbines in the La Guajira desert, ancestral lands of the Wayúu, without informing their communities of planned developments. In other instances, Lawrence (2014) explores "contestations between the Saami people and the Swedish state" over the industrial encroachment of wind power developments on Saami lands, while Hunt and others (2021) debate whether wind power developments in northern Australia "enhance or inhibit" the capabilities of nearby Aboriginal communities.

Negotiations between wind developers and indigenous peoples have yielded diverse results. Native peoples' efforts to block wind farms on tribal lands often fail. While previous research highlights the results and effects of developments on indigenous lands, it frequently does little to explain the methods that wind developers, indigenous peoples, and associated participants use to advance their respective agendas. This research project hopes to explore the methods, failures, and successes of these participants, particularly in the North American region.

Example participants of this research project include wind developers such as Apex Clean Energy, whose goal is to "accelerate the shift to clean energy" (Johnson, 2019) as well as indigenous persons such as elder Tom Ross, who desires to protect the landscape of the Jeffers Petroglyphs, an important cultural site for the Upper Sioux community (Minnesota Historical Society, 2015). Other participants include the Minnesota Commerce Department, responsible for administering permits to wind developers (2021) and the Minnesota Historical Society (n.d.). While the Upper Sioux community and Minnesota Historical Society oppose the proposed Apex wind farm development, the Minnesota Commerce Department must decide whether to allow, modify, or decline the wind farm proposal.

The example participants above highlight just one instance of conflicting agendas between indigenous peoples and wind developers in North America. It is not unordinary to see wind developers finding opposition to projects near protected lands. Clearly, a better understanding of how indigenous peoples and other participants influence the siting of wind developments is important. While wind energy expansion is essential to combatting climate change, awareness of its disturbance to indigenous peoples and their lands deserves careful attention.

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