Prospectus

The Effect of Wind Turbine Blade Design on Energy Efficiency

(Technical Topic)

Actor-Network Theory and Icing on Wind Turbine Blades

(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

Wind energy is one of the fastest-growing energy sources in the world today. In the last 10 years, wind power capacity in the United States has grown about 15% each year and is considered to be the largest source of renewable power ("Advantages and Challenges of Wind Energy"). Wind turbines are used to convert wind into electricity. They each have a set of blades, which varies from one to three. Wind causes the blades to spin, which creates kinetic energy ("How Do Wind Turbines Work"). A box located next to the blades, consisting of a nacelle and a shaft, uses the kinetic energy and converts it into electrical energy. Electrical energy is carried through a transformer that will increase its voltage so that it will move toward the national electricity system, where it can be used in homes and businesses ("How Does A Wind Turbine Work?").

Even though it is renewable, wind energy still has to compete with lower cost sources of electricity. It tends to be inefficient and inconsistent, which dissuades people from using it. Theoretically, based on Betz's Law, maximum wind turbine efficiency is about 59% (Ragheb, 2011). In reality, wind turbines only produce about 30 to 40% of their potential energy output. As a result, wind turbine blades can be used up to 25 years before they are thrown out due to degradation ("Advantages and Challenges of Wind Energy"). To address this issue, a technical solution would be to design a wind turbine with a different blade design that would promote energy efficiency.

Although a technical solution is important in order to address the issues of energy efficiency that come with wind power, it is also important to consider the science, technology, and society (STS) aspect of this issue. Wind energy is often criticized by its users for being unreliable, which can prevent other individuals from wanting to use wind energy and the construction of wind turbines in a certain area. Wind energy is considered unreliable because there are other factors that come into play, such as the climate. Precipitation can add weight to the turbine blades which can cause it to function at a less than optimal performance and cause increased wear (Doagou-Rad, 2019). Some wind farms have started testing de-icing technologies to reduce the precipitation weight on turbine blades, but significant changes throughout the data collection prevented researchers from finding a solution to this problem.

Actor-Network Theory, developed by Bruno Latour, Michel Callon, and John Law, can be used to reveal how human and nonhuman actors within the wind energy network all play an important role. By either fulfilling or voiding their role, these actors have an impact on energy efficiency and the public attitude towards wind energy. This determines the success of wind power being used in a certain area. In order to improve the power efficiency of a wind turbine, both social and technical aspects are important to consider. For the technical project, a wind turbine with an improved blade design from pre-existing ones will be developed. For the STS project, Actor-Network Theory will be used to analyze how actors within a particular wind energy network failed to provide a solution while testing de-icing strategies to prevent power loss in the wind turbines during winter.

Technical Problem

Wind turbine blade designs affect how much wind energy is being captured and used for electricity conversion. Traditionally, flat blades were used in windmills for thousands of years. However, flat blades can resist wind, leading to a slower rotation and less power generation. Curved blades are becoming more common in modern wind turbines. The shape is similar to an airfoil, or an airplane wing. This shape allows air to flow around it, with air moving over the curved side of the blade faster than the flat side. This establishes lower pressure on the top of the blade (Tutorials, 2020). Aerodynamic lifting forces, which are perpendicular to the blade, cause rotation of the blades (Schubel, 2012). These forces allow the wind turbine to generate more power. Drag forces along the blade can prevent motion of the blades, because they act like friction against air (Tutorials, 2020).

Choosing the proper angle of attack is important. The angle of attack is the angle between the direction of the wind and the pitch of the blade with respect to the wind. As the angle increases, more lift force is created. For small-scale wind turbines, 5° is found to work best ("Wind Turbine Blade Design, Flat or Curved", 2020). However, there is a limit around 20°, where the lift force will begin to decrease. Therefore, there is an optimal range of values for energy efficiency. Angles can vary with how much wind velocity there is. A research study conducted in 2017 found that 5° was optimal for a wind velocity of 7 m/s, 20° for a velocity of 15.1 m/s, and 30° for a velocity of 25.1 m/s. However, drag coefficients for unsteady airfoils was found to be a lot higher than static airfoils because of the delay caused by the transition of boundary layers (Kalkman and Blocken, 2017). This is when laminar flow transitions into turbulent flow.

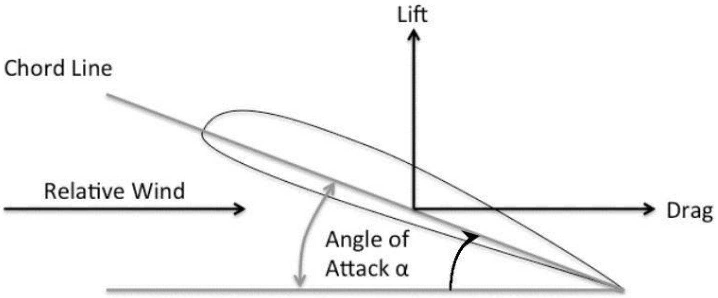

Figure 1: Diagram Showing Angle of Attack Relative to Blade

Tip-to-speed ratio is another factor that can reduce drag forces. It is the ratio of the wind speed and the speed of the tips of a wind turbine. If the ratio is above 1, there are lift forces that cause the blades from spinning faster than the wind speed. If the ratio is below 1, there are drag forces preventing the blades to spin faster than the wind speed. Most modern wind turbines have a tip-to-speed ratio of 5 (“Wind Energy Math Calculations Calculating the Tip Speed Ratio of Your Wind Turbine”, 2015). Currently, the optimal tip-to-speed ratio is around 6 or 7. The maximum energy efficiency achieved with a ratio of 6 is about 45% (“Wind Turbine Tip Speed Ratio”).

Although these factors have been considered in previous blade design experiments, they were not the most optimal designs for energy efficiency. There was still a substantial amount of energy lost. The experiments would often consider only one factor. In reality, wind turbine efficiency is determined by several different factors. By failing to consider all aspects of the blade design, it is difficult to find the most efficient design that would be favorable for residential and commercial use. In this project, blade shape, the angle of attack, and the tip-to-speed ratio will be considered. They were found to have the most impact on the wind turbine’s efficiency in previous experiments. These aspects will be adjusted to the range of values that were found in past blade design experiments and are currently used for wind turbines to be optimal for wind turbine efficiency. A curved blade will be used, with a range of around 5° for the angle of attack and a range of 4 to 6 for the tip-to-speed ratio.

The goal of this technical issue is to design a wind turbine to achieve the maximum efficiency of 50%, which is the highest possible efficiency that previous wind turbines have been recorded to reach (Blackwood, 2016). In order to achieve this, the wind blade shape, the angle of attack, and the tip-to-speed ratio for a wind turbine must be adjusted. Through the creation of this wind turbine, it will be revealed how all of these aspects work together to increase the efficiency of a wind turbine. This can also help shift current attitudes towards wind energy and raise awareness on its benefits.

STS Problem

Caribou Wind Farm in northern New Brunswick, Canada generates enough power to power around 30,000 homes. The cold, winter months cause ice accumulation on the wind turbine blades. In 2012, it was reported that only 11 out of 33 turbines were operating during the winter. In the previous year, the icing became such a significant problem that all of the wind turbines were shut down (Bingley, 2012). This created many customers' concern about the reliability of wind power. It would increase the cost of power bills while leaving many homes and businesses powerless (Weston, 2011). Ice accumulation on the blades causes the wind turbines to operate weaker than usual and wear faster. It affects the structure, leading to a decreased maximum load on the blades. This can prevent the blades from rotating, resulting in lower power generation. This resulted up to 20% of annual energy production losses at Caribou (Froese, 2018).

Wicetec Ice Prevention System (WIPS) is a technology that improves energy production during the colder seasons by preventing ice formation. It consists of fast heaters and ice detection that would detect ice and heat it so that it would prevent accumulation on the blades ("Wicetec Oy", 2019). WIPS was used for testing during the cold months in at Caribou to test whether or not it was effective for use. However, in recent years, researchers at Caribou Wind Farm found that there was a lack of significant icing. This led to testing results that were inconclusive. Additionally, WIPS was very costly to implement; to replace 99 blades, it would cost at least tens of millions of dollars. Other de-icing testing methods, such as electric heated tiles, black paint, helicopter coating, and R&D products were also attempted for testing on the wind turbine blades. They were found to be even less efficient and more expensive (Froese, 2018). As a result, researchers have failed to find an adequate solution to the icing issue. This raises a significant question: How did the wind turbine network at Caribou fail as a result of its human and non-human actors?

The project managers and wind turbine researchers acknowledge their roles as network builders of the wind energy network. Although issues regarding energy efficiency were raised in the New Brunswick community, the experimentation process was poorly planned out. The project managers and wind turbine technicians of Caribou recognize that ice is a large factor in wind turbine inefficiency. They also recognize that the customers of the wind turbine farm are influential in the issues they have with wind energy and its efficiencies. If the customers are unsatisfied, it can cause a decrease in wind energy usage in New Brunswick. They will continue to view wind energy as an unreliable energy source. They fail to acknowledge other factors that contribute to this issue, such as the unpredictable weather changes and the costs of implementing de-icing technologies. These factors brought unexpected changes in the network, causing it to fail. By acknowledging these specific non-human actors, the human actors at Caribou can recognize the importance of non-human actors in the network and develop better solutions to the efficiency problems during the winter.

Actor-Network Theory can be used to analyze the failure of finding an adequate solution for ice accumulation on wind turbine blades at Caribou Wind Farm. This theory examines the power roles that human and non-human actors possess within the networks that they establish and how they influence the networks they build. These actors become involved in the network when the network builders assemble them into the network in order to accomplish a main goal that aligns with their interests. Actor-Network Theory can be applied to Caribou Wind Farm by analyzing the important human and non-human actors in the failed experiments of the Caribou Wind Farm network. The project managers and researchers working on the experiments failed to adapt a de-icing technology because climate changes and costs prevented them from obtaining accurate data and finding an appropriate de-icing technology. The human actors recognized the importance of their roles in the network which established a coherent network and helped identify the problem in the network. However, failing to acknowledge the influential role of certain nonhuman actors led to failure in the network because the human actors were not prepared for changes in the network that were caused by these actors not performing their expected action within the network. This would leave customers unhappy with the wind farm and cause them to find more reliable energy sources to use, creating a negative image for wind power. Overall, it is important to understand the impacts that one small mishap can bring upon an entire industry.

Conclusion

Both the technical and social aspects will address the issues behind the efficiencies of wind turbines. The technical paper will produce a wind turbine with an improved blade design that will attempt to maintain a maximum efficiency of 50%, by adjusting the shape, the angle of attack, and the tip-to-speed ratio of the blades. Additionally, Actor-Network Theory will be used to analyze how researchers at Caribou Wind Farm failed to acknowledge certain non-human actors and their impact on de-icing blade design experiments. This will increase the understanding of how both human and nonhuman actors have a significant role in the networks built under wind energy systems. If at least one actor does not perform its expected role, then the networks will become unstable.

Together, the technical and STS reports will solve the issues that wind turbine creators and users have with the efficiency of wind turbines. By examining the components of the wind turbine blades and other surrounding factors, it will be revealed how they all play a significant role in the efficiency of the wind turbine networks.

Word Count: 2208

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