**Developing a Reliable Active Aerodynamic Control System for Wind Turbines**

**Analysis of Successful Policy for Natural Gas Energy Production and Applications to Renewable Energy Policy**

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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**

*Ask yourself: How does climate change affect you?*

In late 2015, leaders from 196 countries met in Paris, France to discuss just one question: How can we keep global warming and climate change from having destructive, irreversible effects on the environment? They identified greenhouse gas emissions, specifically carbon dioxide, as the cardinal influence on climate change. Just how bad is climate change? A study from the University of Edinburgh (2021) found that from 1994-2017, due to climate change from greenhouse gas emissions, an average of *1.2 trillion metric tons* of ice melts each year, (Slater et al, 2021, p. 1). Global warming effects don't stop at ice. A EPA (2016) report states that by 2100, Eastern Virginia will record temperatures over 100° Fahrenheit for 40 days of the year, 4 times the current number, (EPA, 2016 n.p). Climate scientists, world leaders, farmers, and activists agree: technical, cultural, and organizational changes to the way we think about energy production and consumption are imperative.

Clean and renewable energy like wind turbines, solar cells, and hydroelectric dams, have the capability to replace coal and fossil fuels as our primary source of energy production and consumption. Completely replacing these high emissions fuel sources in electrical power generation would reduce US carbon emissions by 35% or 1.9 billion tons of $CO^2$ (EIA, 2021 p.1). However, policy, regulation, economic, and technical barriers discourage or even prevent the complete implementation of renewable energy projects. There is a need for continual work on the efficiency and cost effectiveness of renewable energy sources, which combined with policy and cultural paradigm shifts, will soften the warming effects of climate change so generations to come can won't suffer the consequences of our inaction.

The technical premise of my research will be to develop an active control system with the purpose of increasing the power generation efficiency of wind turbines over a large range of wind speeds. Additionally, this active control system will be used during the normal operation of the wind turbine to keep it at a constant rotational speed, as to provide a reliably constant frequency of electricity to the national grid. In complement to the proposed technical improvements to wind turbines, my STS research will analyze the key policies, research focus areas, leaders, and organizations that have led to the explosion of alternative fossil fuels, such as natural gas, and the relative failure of wind and solar power. I aim to use these lessons to lay out how these actors must synergize their efforts in the coming renewable energy era.

**Developing a Reliable Active Aerodynamic Control System for Wind Turbines**

For the last few decades, wind turbine manufacturers have used pitch control, 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 wind speed at which a turbine produces its rated power, and allow the turbines to spin at a constant rotational speed during its rated power phase (Muljadi & Butterfield, 1999 p.323). 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 p.22). 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 p.23).

The mission of our project is to develop and prototype an active control system effective at increasing both the efficiency and reliability of the GE 2.78MW-120m turbine across wind speeds from 3m/s to 20.5m/s. As shown in the figure below, these wind speeds represent the cut-in and cut-out wind speeds that define the operating range for this turbine (Bauer & Matysik, 2021 n.p).

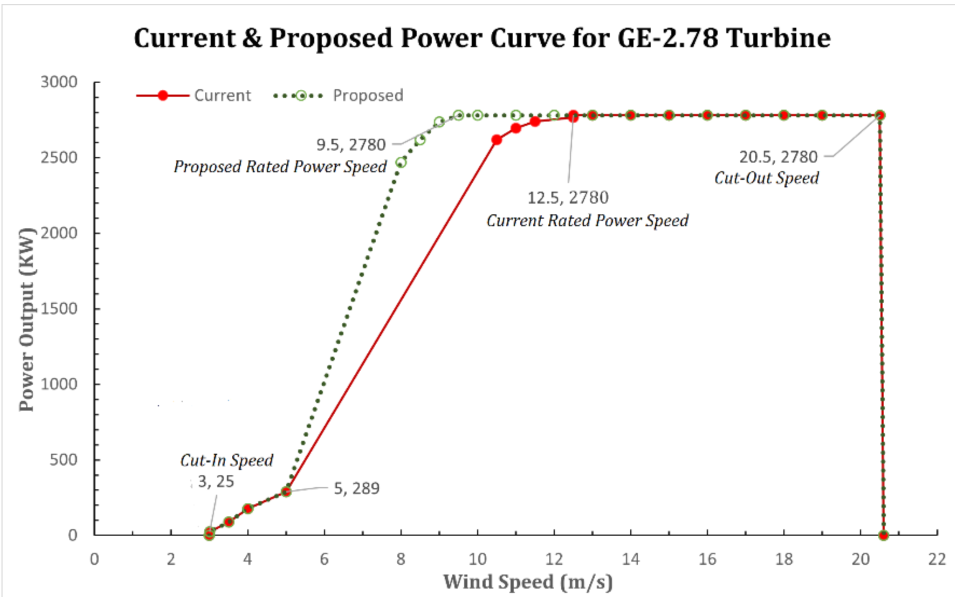


**Figure I. Current & Proposed Power Curve for GE-2.78 Turbine.**
*Shows the data on rated power wind speed, and the improvements our team hopes to make with new system. (Created by Author)*

From Figure I, 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 I, our goal is to decrease the rated power wind speed from 12.5m/s to 9.5m/s. Our preliminary analysis shows that this would result in an 6% increase in annual electrical power generation.

In our team's system selection process, we will consider manufacturing costs, system simplicity, performance improvements, and system reliability. Our team will create 3D CAD models of our proposed control system using SOLIDWORKS software and validate the mechanism and control system by leveraging high power analysis tools, such as WISDEM and OpenFAST, built and developed by the DOE specifically for wind turbine aerodynamic analysis. Furthermore, we will 3D print and prototype our mechanism into a scaled down turbine, which will be verified using wind tunnel testing. Finally, we will complete a failure mode & effects analysis (FMEA) and levelized cost of energy (LCOE) analysis to evaluate the importance of our solution to the turbine manufacturing industry.

## Analysis of Successful Policy for Natural Gas Energy Production and Applications To Renewable Energy Policy

As stated, in recent decades, *need* for the primary source of energy production in the United States to be clean and renewable has become quite apparent through increasing evidence of climate change and a limited supply of current energy production resource; however, the *path* to achieve a clean, renewable energy future, has yet to be determined. The disagreements and disorganization of policymakers, corporations, and public pressures on the proper path to an emission free electricity system have led to a significantly higher rate of natural gas projects, and a comparatively lower rate of wind, solar, and hydroelectric project (EIA, 2021 n.p). While the use of natural gas may slow the rate of carbon emission fractionally, it is in no way a solution to a meet current U.S. emission goals (Crow et al, 2019 p.6)**.**

The dramatically falling costs of natural gas and existing technologies that make producing energy from natural gas efficient, cost effective, and reliable, make it a clear choice for many electrical energy generation plants. According to the US Energy Information Administration, natural gas now constitutes over 40% of energy production in the US, while renewables lag at 20%. Shockingly, just three decades earlier, in 1990, natural gas and renewable energy each accounted for only 8% of energy production in the US (EIA, 2020 n.p). However, it isn't just the cheap costs of natural gas that has burgeoned its popularity and utilization. According to analysis from the Nuclear Energy Institute, through 2016, the federal government offered $84 billion in tax incentives for renewable energy production, but *over $122 billion* in tax incentives for natural gas energy production (MISI, 2019 p.83). These tax deductions for natural gas come in the form of direct drilling cost deductions and "nonconventional fuel tax credits" meant to encourage domestic energy production (Coleman et al., 2019 n.p). Policymakers have made it even easier for electricity production companies to shy away from utilizing available renewable energy resources. Even today, the federal government and electrical energy production corporations taut that natural gas is "a relatively clean burning fossil fuel" as it releases about 45% less carbon than coal and 30% less carbon than oil when burned (Di Pascoli et al., 2019 n.p). The key word is in this statement is "relative", as burning natural gas releases 3900% more carbon dioxide than power generation via wind turbines. However, the statements regarding natural gas from government and energy corporations lead energy consumers to believe natural gas is a proper alternative to other fossil fuels. In fact, according to a study from the Pew Research Center, 72% of adults in the US are in favor of expanding natural gas (Kennedy et al., 2019 n.p).

There is a fundamental economic and organizational support in the growth of natural gas energy in the last few decades, evident in tax policies, public opinion, and corporate energy vernacular. My project deliverable will be an analysis of the successful key federal policy, research developments, and organizational efforts that have led to the explosion of natural gas energy production, and how lessons from these can be applied to adjust our current renewable energy policy to power into an emission free, renewable future for the United States.

**Conclusions**

It's critical we take action to mitigate the emission of greenhouse gasses and preserve the environmental integrity of Earth. My project hopes to contribute by making renewable energy the obvious choice for electrical energy generation by improving efficiency, reliability, cost effectiveness, and popularity of wind turbines. I also hope my research will serve as evidence and inspiration for immediate action from policymakers, regulators, and corporations to take carbon emissions seriously and make evidence-based adjustments to energy policy, regulation, and paradigms. Through the synergistic efforts of these actors, *together we can defeat climate change.*

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