Improved Yaw Control Strategies Using LIDAR Preview and Alternative Algorithms

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Wind Turbine Introduction

Renewable Energy

- Wind turbines are a proven, reliable source of renewable energy
- Improving their efficiency could lead to more widespread use

Control

- Generator Torque, Blade Pitch, Yaw
  - Yaw control is the means by which the blades are rotated about the vertical axis to face into the oncoming wind gust
- Besides physical manipulation of the turbine, perfecting control strategies is how wind turbines are made more efficient.
  - The current NREL yaw controller is based on aggregating the squrre of the yaw error (angular difference between wind direction and turbine heading). After the threshold is reached, yaw correction is initiated.

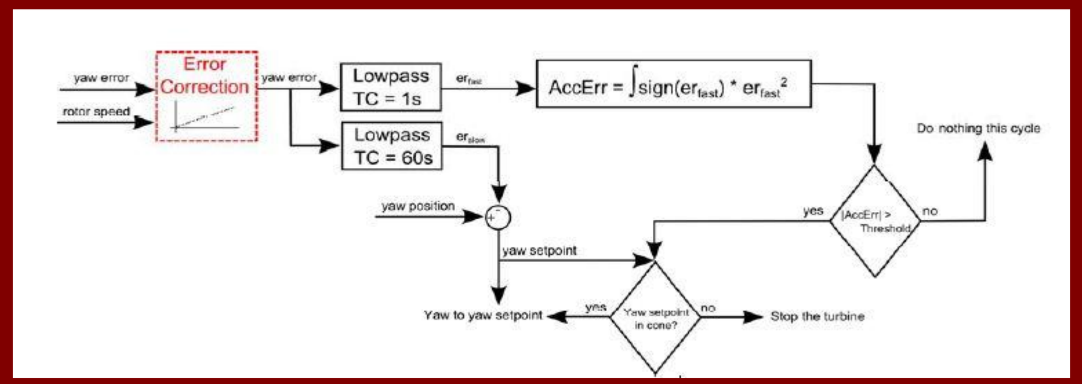

Figure 1: This is a schematic description of the NREL baseline yaw controller [2].

LIDAR

- An optical ranging device similar to RADAR
- If mounted on a wind turbine, there could be a benefit of knowing changes in wind speed and direction before they happen at the turbine.

Figure 2: This image gives a visual of a LIDAR device mounted on a wind turbine [3].

Overview

Issue: Slow yaw speed of utility scale wind turbines causes a slow reaction to large changes in direction. However, yawing due to small changes in wind direction is also inefficient.

Objective: Show benefits on power generated and structural loading through simulations of the CART3S turbine using the developed controllers.

Process: Perform simulations of the CART3S wind turbine using the FAST design codes from the NREL website. The blade pitch and generator torque controllers were designed by Shu Wang. The wind case that will be focused on is the Extreme Direction Change as described in the Germanischer Lloyd wind turbine guidelines [1]. This is a 45 degree change in wind direction over 15 seconds, which occurs at 150 seconds in the simulations. From trial to trial, the active yaw controller will be varied. A description of the different yaw controllers used can be found in the Alternative Strategies section.

Conclusions: As shown in the LIDAR Preview section, the results of these simulations support the hypothesis that LIDAR preview on wind turbines will make them more efficient from a power standpoint and last longer due to the structural loading undergone. Also, as shown in the Alternative Strategies section, both developed strategies would produce more power and last longer due to the structural loading.

Opportunities for Further Research

- Recently, the University of Minnesota partnered with Mesabi Range Community and Technical College and used their Vestas V27 wind turbine for research purposes
- This makes it possible to test the developed yaw control strategies on an actual turbine without the approximation of the Extreme Direction Change wind gust case used in simulation. It is also ideal to test these new strategies on this smaller turbine than on the Clipper Liberty turbine at UMore Park.

Figure 7: This is a picture of the Vestas V27 turbine at Mesabi Range Community and Technical College [5].

Figure 8: This is a picture of students in the wind energy technology program at Mesabi Range Community and Technical College. This image shows the technical experience these students gain by having a wind turbine at their access.

LIDAR Preview

The results of the varying amounts of preview support that implementing LIDAR with the NREL baseline would benefit both the amount of power generated (Figure 3) and the lifetime of wind turbines (Figure 4).

- Figure 4 shows there is a relationship between the amplitude of the change in moment and the amount of preview time. Due to the Paris Equation [4], the amplitude of a cyclic stress is inversely proportional to the cycles to failure. Therefore, the lower amplitude seen in the case of preview suggests wind turbines would have longer performance lifetimes if LIDAR preview was implemented.

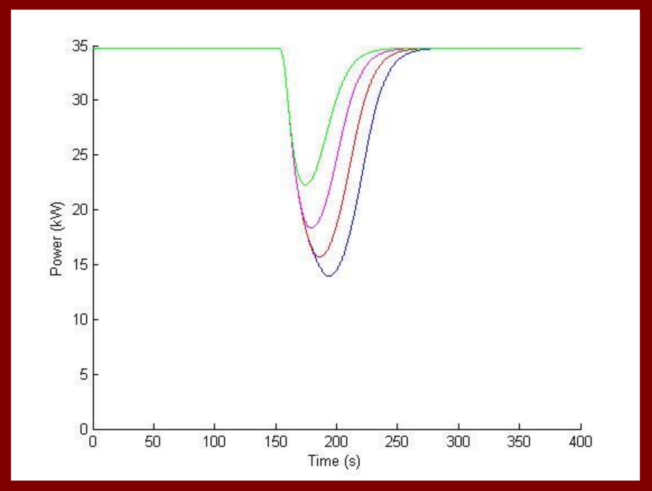

Figure 3: This plot shows results for the baseline controller (blue), baseline with 10 seconds of preview (red), baseline with 20 seconds of preview (magenta), and baseline with 30 seconds of preview (green). This shows the generated power as it varies with time.

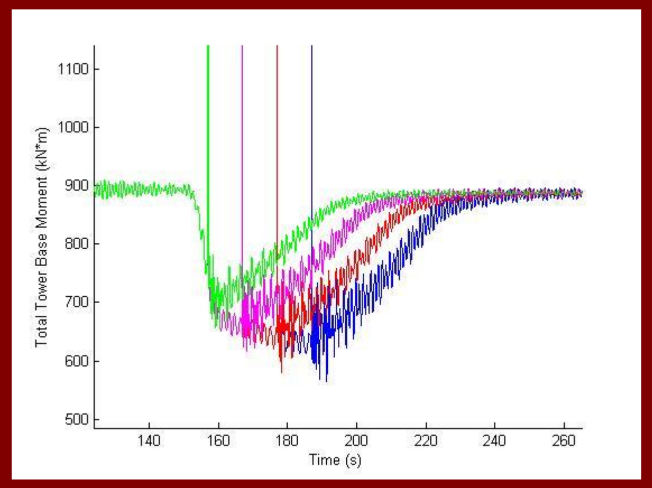

Figure 4: This plot shows results for the baseline controller (blue), baseline with 10 seconds of preview (red), baseline with 20 seconds of preview (magenta), and baseline with 30 seconds of preview (green). This shows the total tower moment about the base of the tower as it varies with time.

- Figure 3 shows there is a relationship between the drop in power when the wind direction changes and the amount of preview time. This clearly shows that the more preview time is implemented, the more power is generated for the extreme direction change case.

Alternative Strategy

The new strategies tested can be described as: alternative one changes the square dependency in the baseline to a cube dependency, which makes the controller more sensitive to larger yaw errors, and alternative two modifies the baseline controller in that it yaws automatically if the yaw error exceeds 25 degrees, which also makes the controller more sensitive to large yaw errors.

- Figure 6 shows that both alternatives have a smaller change in bending moment suggesting, again due to Paris' Equation, that these strategies would result in longer lifetimes in wind turbines that they are implemented.

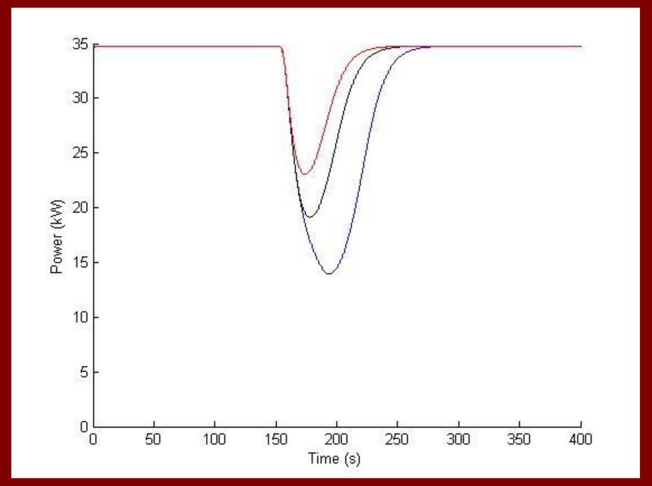

Figure 5: This plot shows the results for the baseline controller (blue), alternative one (black), and alternative two (red). This shows the generated power as it varies with time.

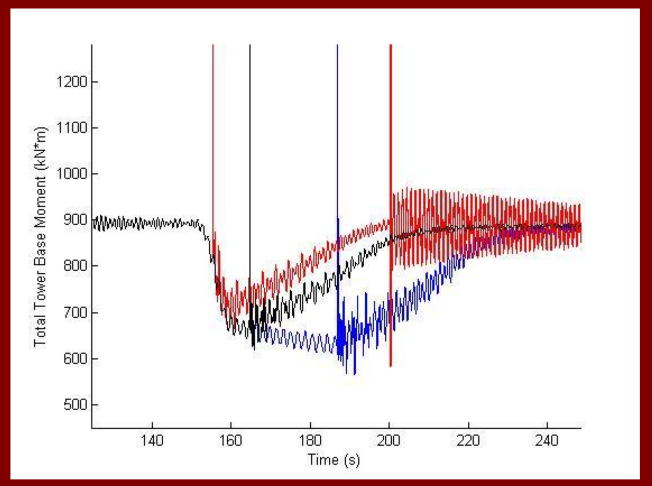

Figure 6: This plot shows results for the baseline controller (blue), alternative one (black), and alternative three (red). The plot displays the total bending moment about the base of the tower as it varies with time.

- Figure 5 shows that both alternatives would produce more power than the baseline controller since their drops in power are both more shallow than that of the baseline controller.
- Furthermore, alternative two is shown to be more efficient from both a loading and a power output standpoint. This is true for the Extreme Direction Change case that was tested, but there is reason to doubt its effectiveness in less extreme situations because or its reliance on a hard switch. Hard switches can be inefficient in measurements that include a lot of noise, such as wind measurements.

References

1. Germanischer Lloyd, “Guideline for Certification of Wind Turbines,” Chapter 4, 2010
2. K. Kragh, and P. Fleming, “Rotor Speed Dependent Yaw Control of Wind Turbines Based on Empirical Data,” AIAA Aerospace Sciences Meeting, January 2012
3. Peach, Matthew. *Lidar Optimized*. Digital image. *optics.org*. SPIE Events Europe Ltd., 13 June 2012. Web. 14 Jan. 2013. http://optics.org/news/3/6/16.
4. Callister, William D., and David G. Rethwisch. "Chapter 8: Failure." *Materials Science and Engineering*. New York, NY: Wiley, 2011. 242-64. Print.
5. Picture of MRCTC Wind Turbine. Digital image. *Mesabi Range Community & Technical College* -- *Welcome to the Wind Energy Program Page*. Mesabi Range Community and Technical College, n.d. Web. 14 Jan. 2013. <http://mesabi.windenergy.project.mnscu.edu>.