# An Overview of Lidar-Assisted Control PART III

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Main questions today

➤ How can we obtain useful information for controls from lidar systems? → Part I

➤ How can these signals be used to improve wind turbine control? → Part II

➤ What are practical considerations when implementing lidar-assisted control in the field? → Part III

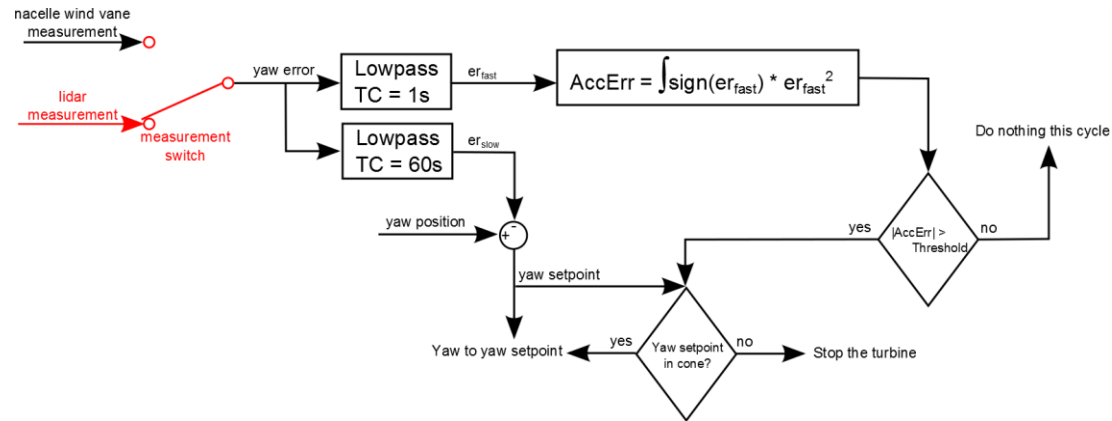# Controls Advanced Research Turbines (CARTs)


Photo by Andy Scholbrock, NREL

- ~40 meter rotor diameter
- Heavily instrumented
  - Dedicated met mast
  - Strain gauges
  - Accelerometers
- ~37 meter hub height
- ~600 kW rated power
- Numerous lidar field campaigns
- Can be run in a downwind configuration
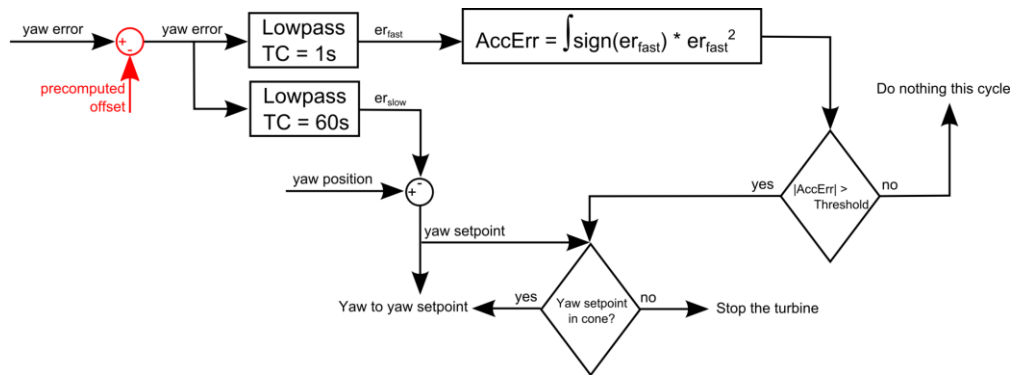
# Lidar Assisted Yaw Control – Bias Correction



Photo by Lee Jay Fingersh, NREL



A. Scholbrock, P. Fleming, A. Wright, C. Slinger, J. Medley, and M. Harris, "Field test results from lidar measured yaw control for improved yaw alignment with the NREL Controls Advanced Research Turbine," in Proc. 33rd Wind Energy Symposium AIAA SciTech Conference, Kissimmee, Florida, USA, January 2013.

# Lidar Assisted Yaw Control – Bias Correction



Photo by Lee Jay Fingersh, NREL

P. A. Fleming, A. K. Scholbrock, A. Jehu, S. Davoust, E. Osler, A. D. Wright, and A. Clifton, "Field-test results using a nacelle-mounted lidar for improving wind turbine power capture by reducing yaw misalignment," Journal of Physics: Conference Series, vol. 524, no. 1, 2014.

# Lidar Assisted Yaw Control – Bias Correction
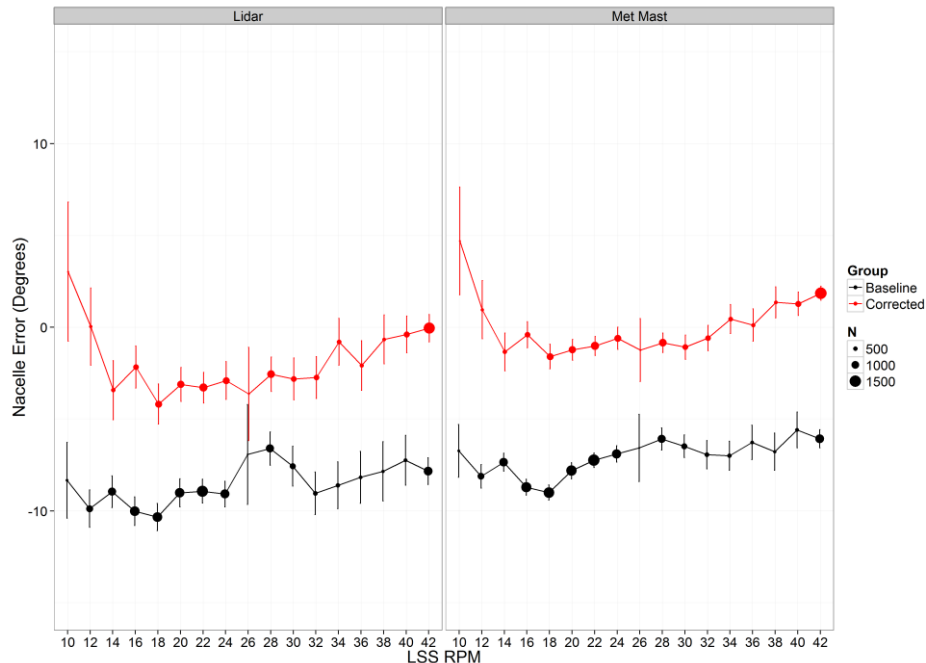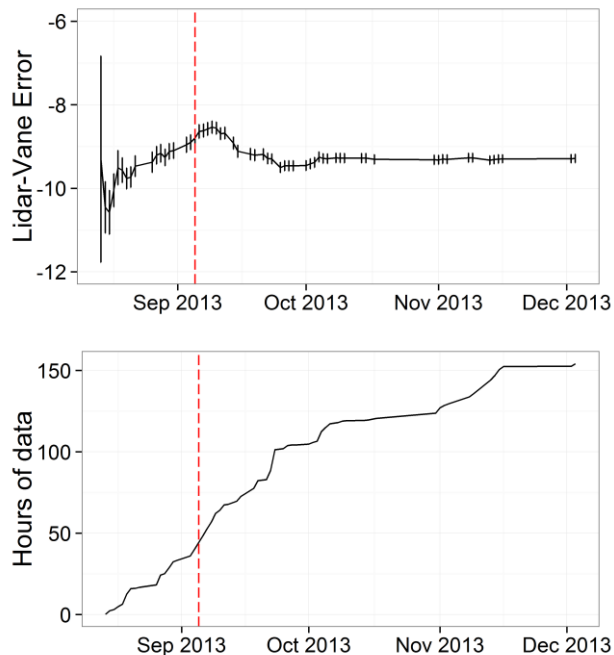


Annual Energy Production estimated to be increased by **2.4%** for a 7.5° static misalignment

P. A. Fleming, A. K. Scholbrock, A. Jehu, S. Davoust, E. Osler, A. D. Wright, and A. Clifton, "Field-test results using a nacelle-mounted lidar for improving wind turbine power capture by reducing yaw misalignment," Journal of Physics: Conference Series, vol. 524, no. 1, 2014.

# Feedforward blade pitch control



Photo by David Schlipf, SWE

- Wind Measurement → Filter Measurement → FF Pitch Control
  - Filter out high frequency content of wind
  - Control generator speed for low frequency
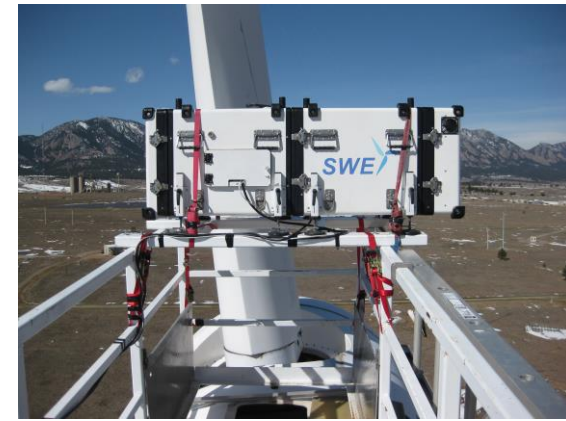  - De-tune conventional feedback control to focus on higher frequency turbine loading controls



David Schlipf, Paul Fleming, Florian Haizmann, Andrew Scholbrock, Martin Hofsäß, Alan Wright, and Po Wen Cheng, "Field Testing of Feedforward Collective Pitch Control on the CART2 Using a Nacelle-Based Lidar Scanner," Journal of Physics: Conference Series, Volume 555, December 2014.
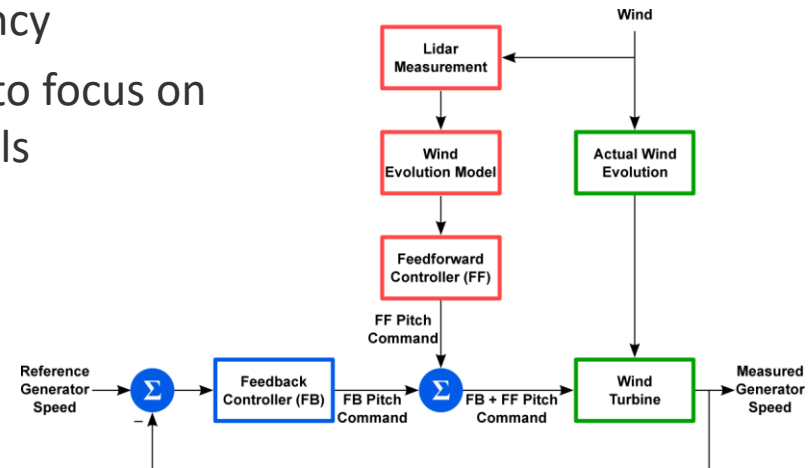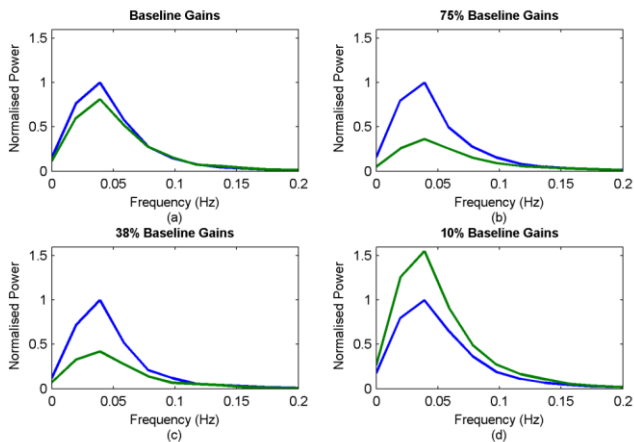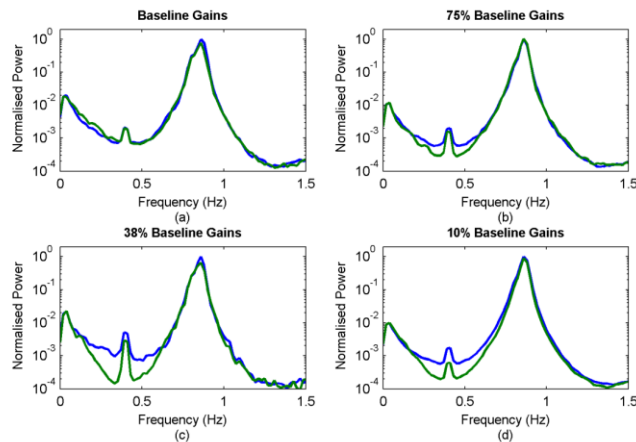
# Feedforward blade pitch control

PSD of Rotor Speed

PSD of Tower Fore-Aft Bending



Blue – Baseline feedback only control
Green – Lidar assisted feedback/feed-forward
control

A. A. Kumar, E. A. Bossaynı, A. K. Scholbrock, P. A. Fleming, M. Boquet, and R. Krishnamurthy, "Field testing of lidar assisted feedforward control algorithms for improved speed control and fatigue load reduction on a 600kw wind turbine," in EWEA 2015 Conference Proceedings, Paris, France, November 2015.

# Practical Considerations from Field Testing

Visibility/Hard Targets

Environment

Static/Dynamic Alignment



Photo by Lee Jay Fingersh, NREL

Photo by Andy Scholbrock, NREL

Photo by Mark Murphy, NREL

# Practical Considerations from Field Testing

## Visibility/Hard Targets



Photo by Lee Jay Fingersh, NREL

## Environment



Photo by Andy Scholbrock, NREL

## Static/Dynamic Alignment



Photo by Mark Murphy, NREL

# Certification of Lidar Assisted Control

- Yaw controller changes
  - Loads considerations
- Feedforward Pitch Control
  - Loss of lidar signal
  - Fallback controller
  - Turbine derating
- Process needs to exist for lidar assisted control to have industrial adoption



Photo by Andy Scholbrock, NREL

David Schlipf, Nikolai Hille, Steffen Raach, Andrew Scholbrock, and Eric Simley, "IEA Wind Task 32: Best Practices for the Certification of Lidar-Assisted Control Applications," Journal of Physics: Conference Series, Volume 1102, October 2018.

# Field Testing LAC Summary

- Wind turbine yaw alignment can be improved using lidars over conventional nacelle vanes

- Feedforward controller can be used to regulate rated rotor speed in region III

- Feedback controller can be tuned for loads reduction

- Yaw alignment and feedforward control can be done in tandem

- Practical considerations of visibility, environment, and alignment need to be accounted for

- Certification process needed to ensure robust turbine operation



Photo by Dennis Schroeder, NREL

# Thank you for your time



Photo by Andy Scholbrock, NREL