Review of LiDAR-assisted control for floating wind turbine applications

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Organized by FWE Quest Offshore

Agenda

- **Introduction**
- **Key findings from fixed turbine studies**
- **Fixed vs. floating turbine dynamics**
- **Floating wind applications & findings**
- **Summary & Conclusions**

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160+
year history

60+
countries

Involved in
>70%
of all operational European offshore wind projects

ENR #1
International Design Firm

AA leader rating from MSCI for environmental, social and corporate governance

Our Strategic Objective

Being a **premium**, **differentiated** business delivering **exceptional** returns for our clients, our team, our investors, and the communities in which we work.

What we do

World leading consulting and engineering company across **energy** and the **built environment**, with **200+ experts** engaged in offshore wind

Our Purpose

Unlocking **solutions** to the world's most critical **challenges in offshore wind.**

Our Vision

Inspire with ingenuity,
partner with agility,
create new possibilities.

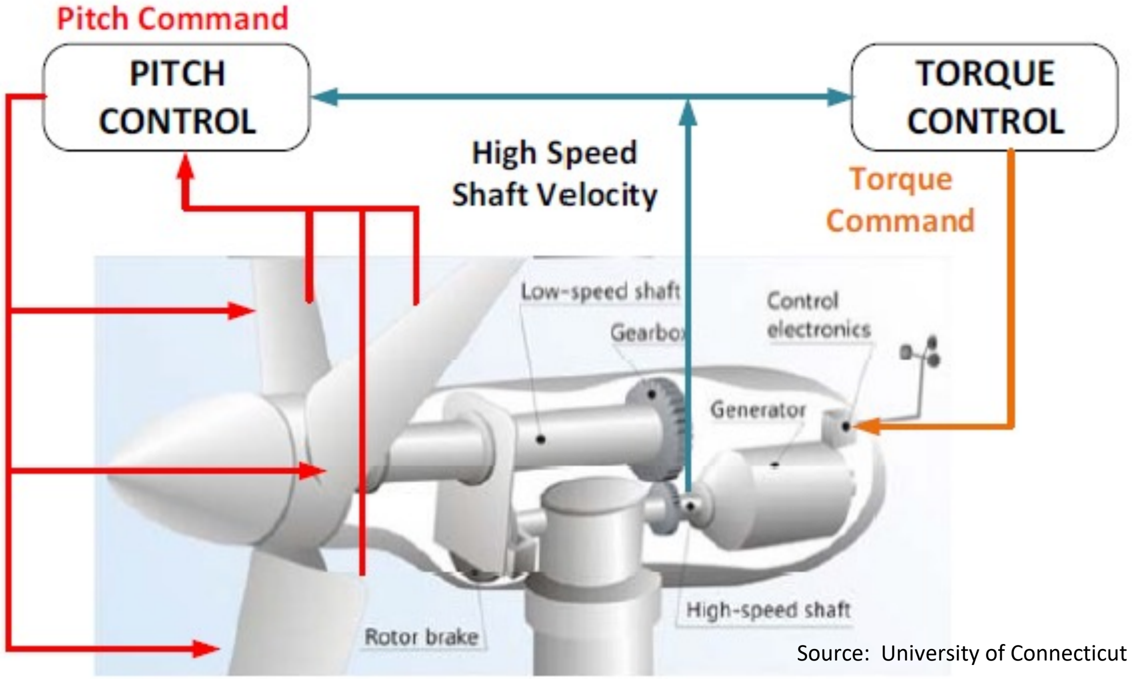
Our Values

Care. Commitment. Courage.

Introduction

Traditional Wind Turbine Operation & Control

- Modern wind turbines are large & flexible structures, which creates a major challenge for offshore wind turbines.
- There are three separate control loops in wind turbine systems: **pitch**, **torque**, and yaw.
- Trade-off between the maximum energy captured and the load induced on the system.



Source: University of Connecticut

Introduction

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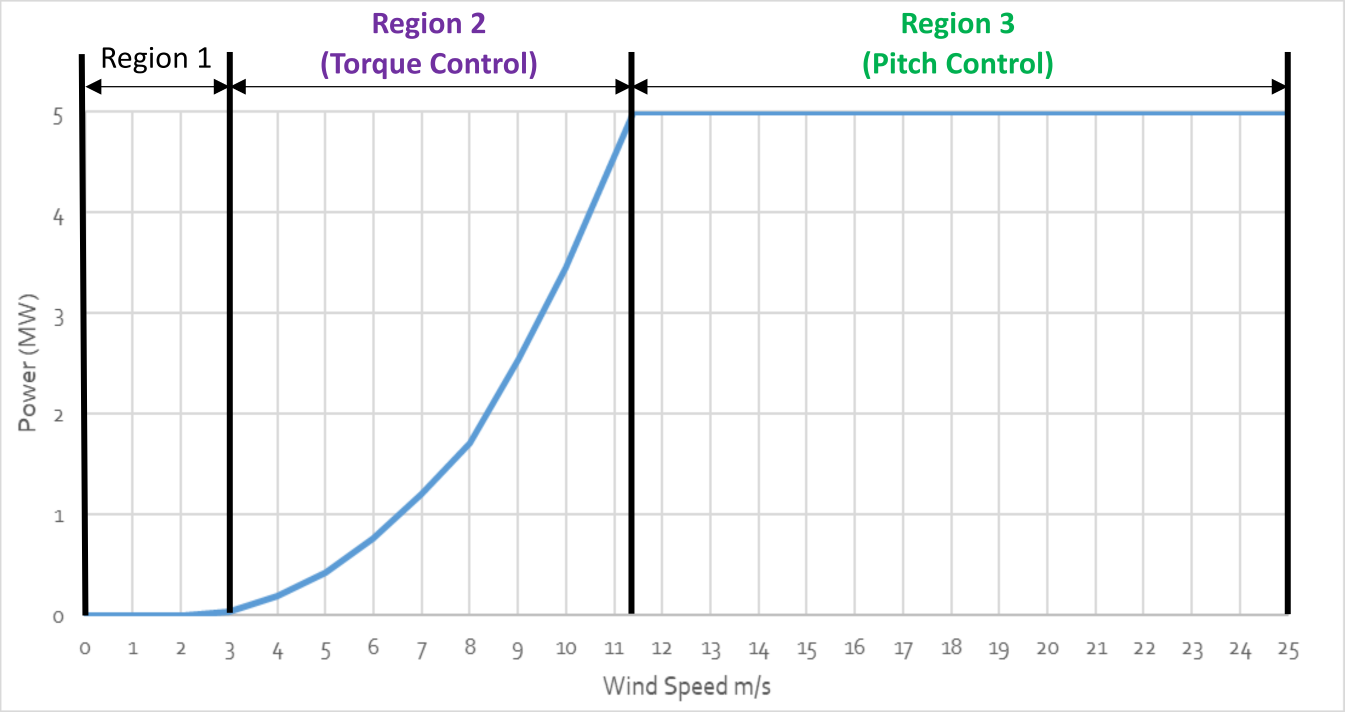
Traditional Wind Turbine Operation & Control

- Turbines are typically categorised into 3 operating regions.
- In Torque (Region 2) and Pitch (Region 3) control, Proportional-Integral (PI) controllers are used.
- Generator speed used as the feedback input.
- Yaw control aligns the turbine nacelle with the wind direction.

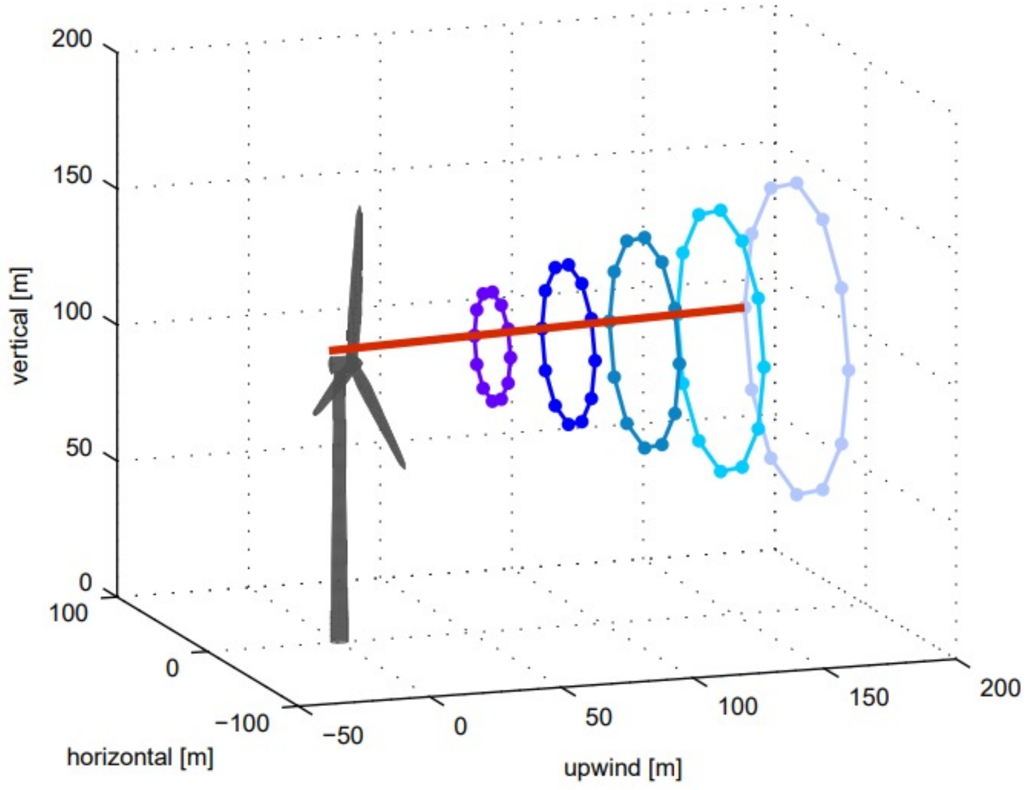


Source: J. Jonkman, S. Butterfield, W. Musial, G. Scott. Definition of a 5-MW reference wind turbine for offshore system development. National Renewable Energy Lab.(NREL), Golden, CO (United States); 2009.

Introduction

Light Detection And Ranging (LiDAR)

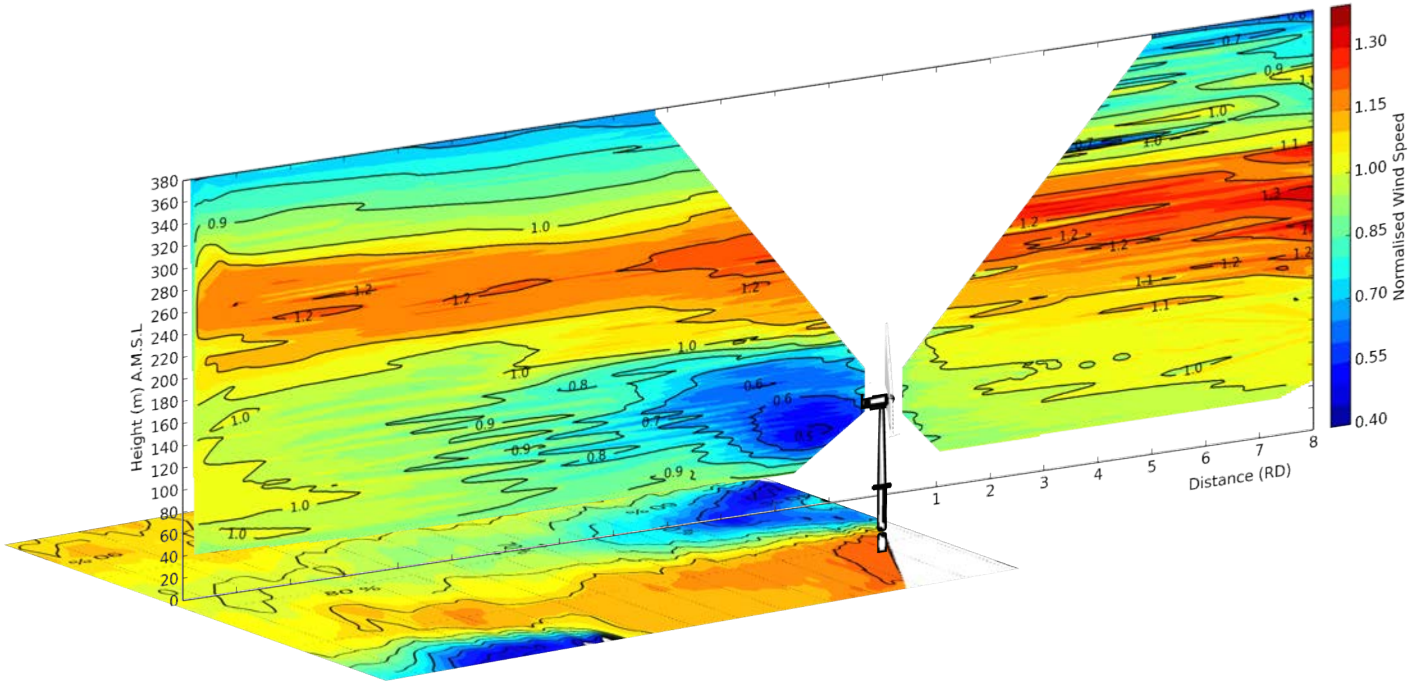
- Operates by firing high speed laser pulses, which are reflected by particulates in the air.
- Nacelle-mounted, forward-looking LiDAR can be used to measure the incoming wind to assist with wind turbine control.
- Two LiDAR configurations – Continuous wave and Pulsed.
- Demonstrated ability to detect wind shear, veer and track gusts during a measurement campaign at the Alpha Ventus wind farm.

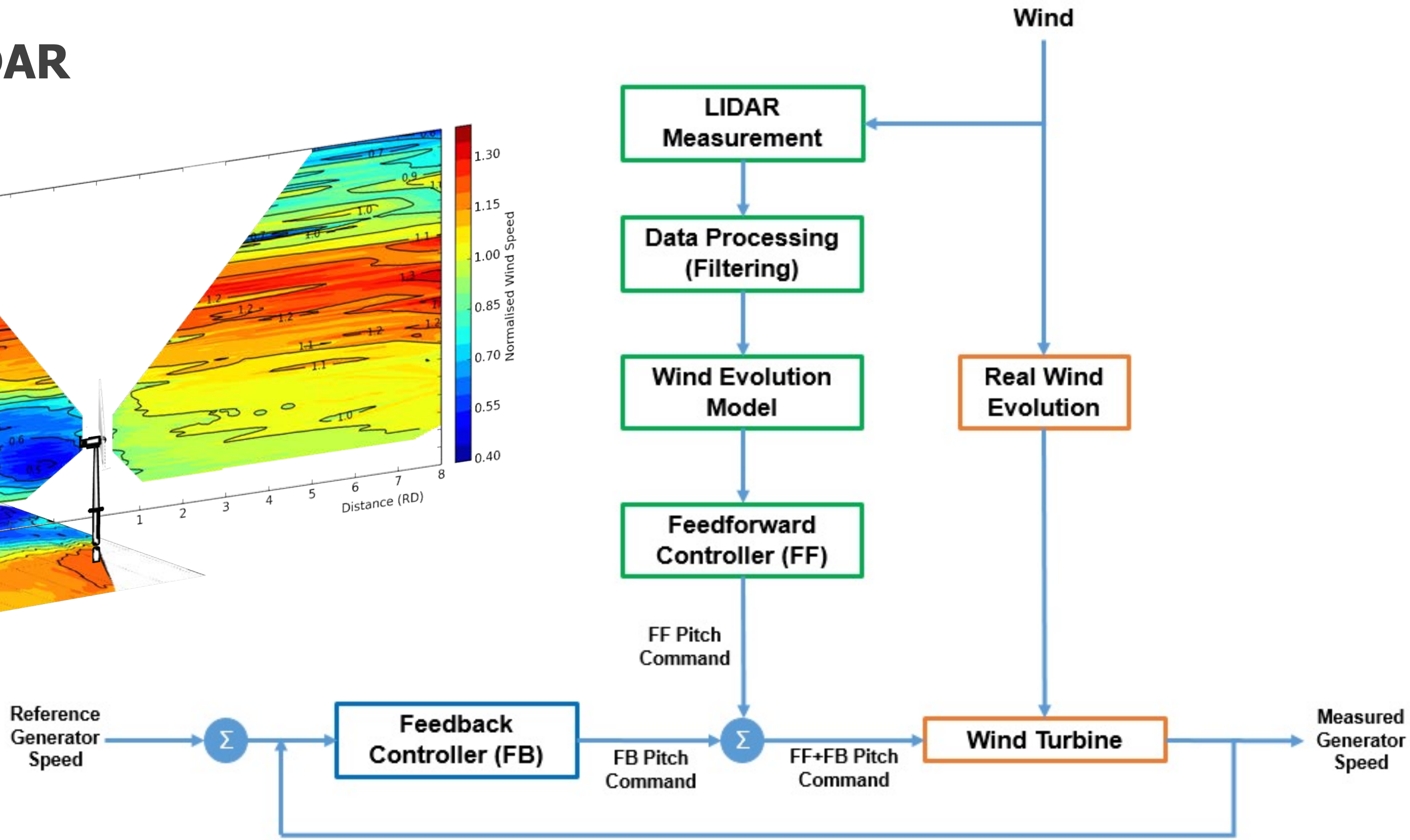


Source: F. Dunne, D. Schlipf, L. Pao, A. Wright, B. Jonkman, N. Kelley, and E. Simley. Comparison of two independent LIDAR-based pitch control designs. In50th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, page 1151, 2012.

Introduction

Turbine Control with LiDAR





Flowchart adapted from: A. Scholbrock, P. Fleming, D. Schlipf, A. Wright, K. Johnson, and N. Wang. LIDAR-enhanced wind turbine control: Past, present, and future. In 2016 American Control Conference (ACC), pages 1399–1406. IEEE, 2016.

Key findings from fixed turbine studies

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Pitch Control with LiDAR [1, 2, 3]

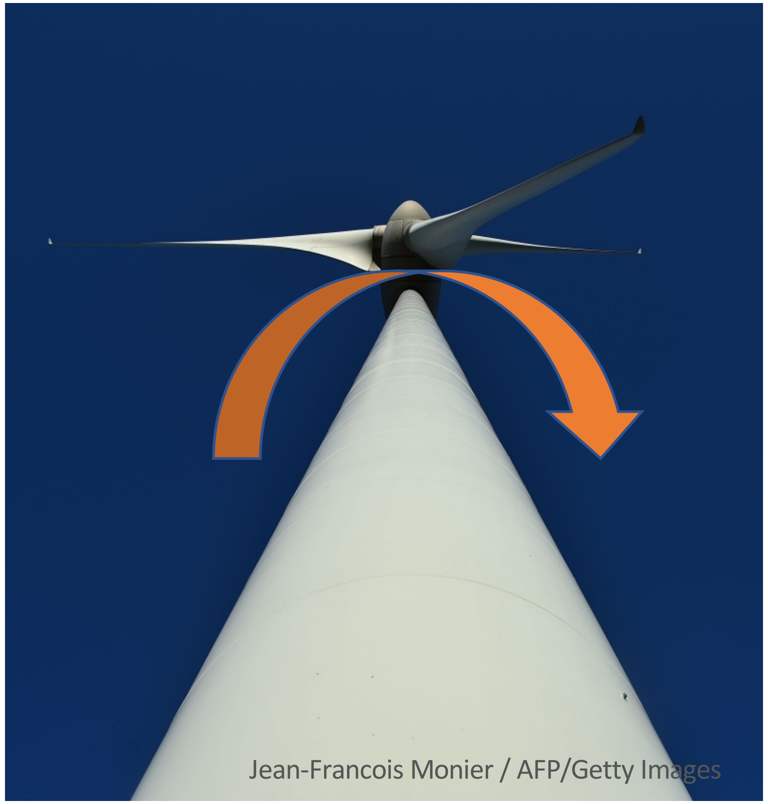
- Disturbance Accommodating Controller (DAC) + LiDAR vs. DAC:
  - Damage equivalent flap loads reduced by ~10% under turbulent wind conditions.
- Feedforward-Feedback vs. Feedback:
  - Standard deviation of the rotor speed reduced by 70-80%.
  - Reduced fatigue and extreme loads on the tower, drive train and blades, without increasing the pitch rate.
  - Positive impacts on rotor speed regulation as well as on tower, blade & shaft loads.

Image source: ABB.com

Key findings from fixed turbine studies

Yaw Control with LiDAR [6, 7]

- Field testing 0.6MW WTG with vs. without error correction applied:
  - Practical wind vane error correction determination showed significant increase in power capture.
  - Positive & negative impacts upon loadings.
- LiDAR vs. wind vane yaw controller:
  - Typical wind vane yaw controller = yaw misalignment *(almost always require static yaw correction)*
  - LiDAR controller yaw misalignment much closer to zero, with superior alignment verified via power performance analysis.



Jean-Francois Monier / AFP/Getty Images

Key findings from fixed turbine studies

Benefits of WTG Control with LiDAR

- Reductions in the **fatigue and extreme loads** on the tower, drive train and blades, without increasing the pitch rate.
- Positive impacts upon rotor speed regulation.
- Significant **increase in power capture.**
- LiDAR controller **yaw misalignment much closer to zero**, with **superior alignment** verified through a power performance analysis.

Fixed vs. Floating turbine dynamics

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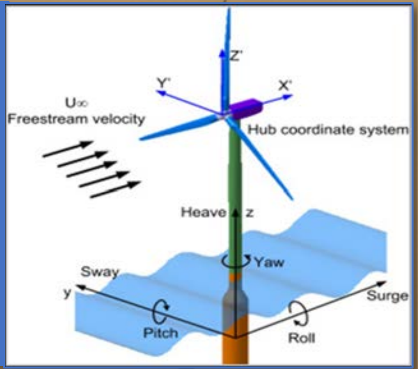
Credit: Paul Anderson

Increased loads on offshore turbine components vs. onshore turbines[8]

Coupling between platform motion & pitch control results in negative damping[9][10][11]

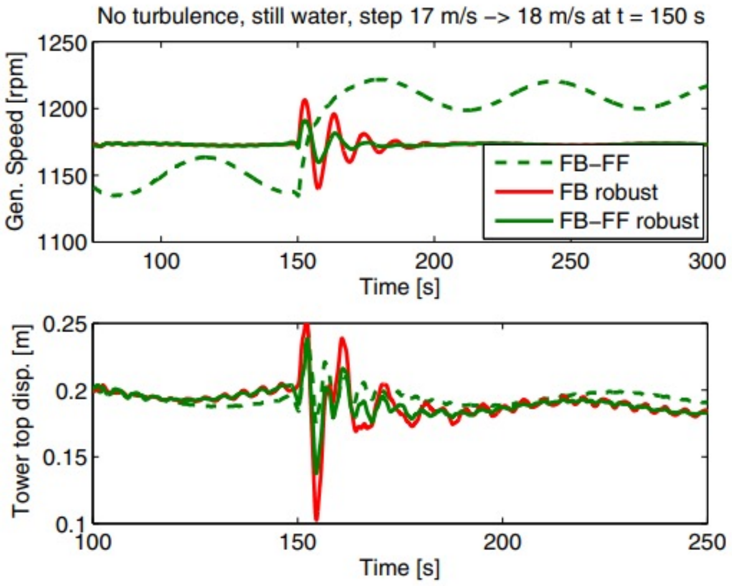


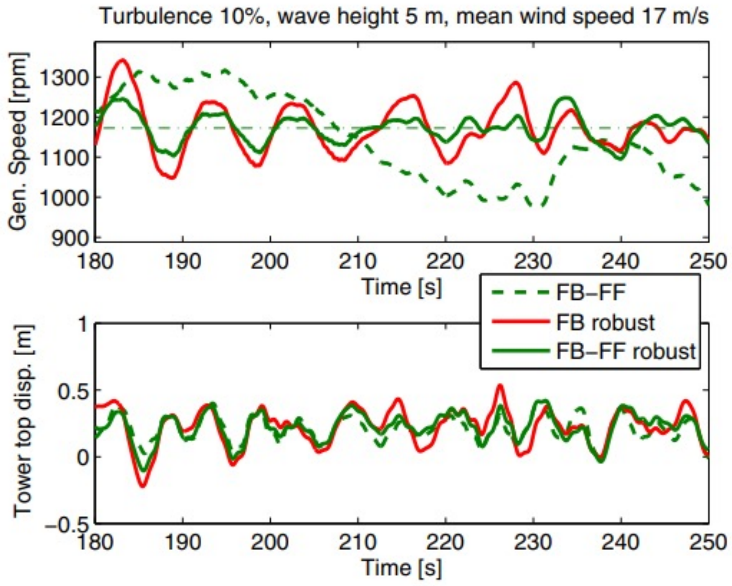
Cost implications

Floating wind applications & findings

Feedforward Feedback Pitch Control of TLP-supported 5MW WTG[12]

- Wind speed step change: Reduction in extreme generator speed variation by 45% and the extreme tower displacement by 40% vs. feedback-only control.
- Turbulent wind field, 5m significant wave height: Standard deviation of the generator speed reduced by 44%. Standard deviation of the loads reduced by 24% vs. feedback-only control.



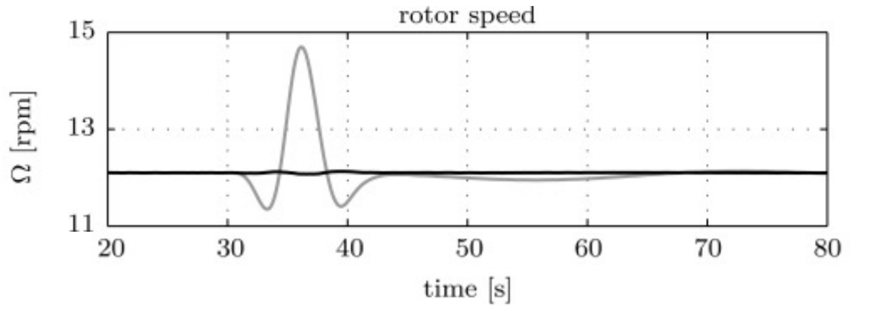


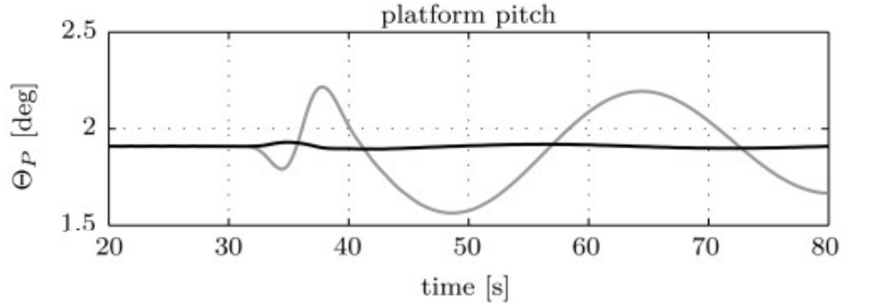
Floating wind applications & findings

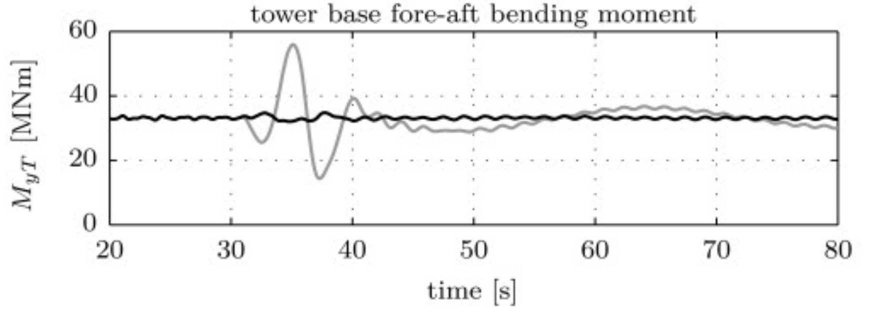
Feedforward Feedback Pitch Control of Spar-supported 5MW WTG[12]

Perfect wind preview (vs. baseline):

- Rotor speed overshoot **reduced by 98.9%**.
- Maximum platform pitch angle deviation **reduced by 93.7%**.
- Maximum tower base fore-aft bending moment **reduced by 37.8%**.





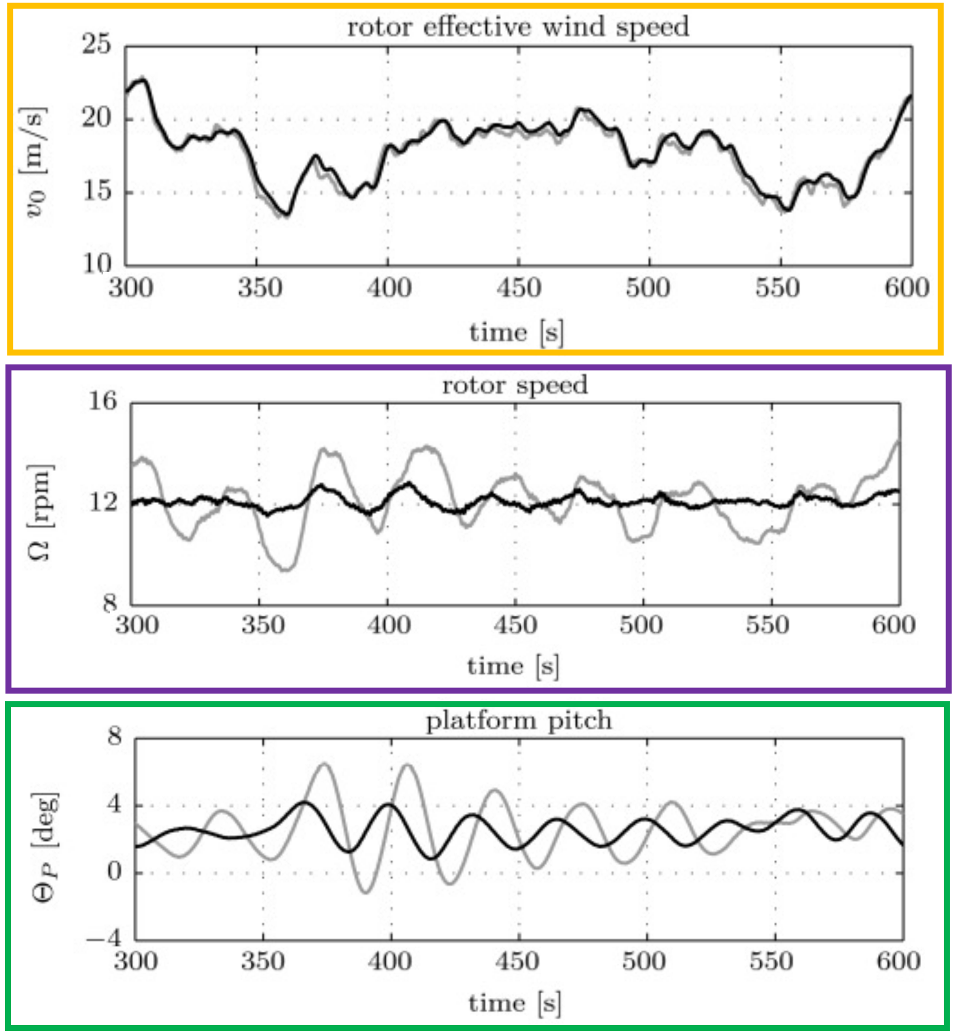


Floating wind applications & findings

Feedforward Feedback Pitch Control of Spar-supported 5MW WTG[13]

Realistic wind preview (vs. baseline):

- LiDAR able to capture the rotor effective **wind speed**.
- Reductions in **rotor speed variation**, **platform motions** and **tower base bending moment**.
- Loading reductions: Tower base loads by 20%, shaft loads by 7%, and blade root by 9%.



Floating Wind *Solutions*

Summary & Conclusions

- LiDAR-assisted control of floating wind turbines will be a part of our efforts in reducing TOTEX
  - Goal is to, by 2040, reduce CAPEX by 65% and OPEX by 36%
- Proactive vs. reactive control = where the industry is going
- CAPEX impacts include more efficient floater designs.
- OPEX impacts include less maintenance leading to reduced OPEX, as well as less exposure to risks for service personnel.

Summary & Conclusions

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Design

- Studies of larger turbines to reflect the commercial landscape
- Studies into Semi-Submersible designs
- Impacts for substructure and turbine design

Control

- Feedforward individual pitch control
- Knowledge of incoming waves for feedforward control
- Yaw control

Commercial

- Commercial deployments of LiDAR for wind turbine control
- Assessment of cost reductions from implementation of LiDAR-assisted control

Thank you!

References & Acknowledgements

Andrew Russell, Maurizio Collu, Alasdair McDonald, Philipp Thies, Alan Mortimer and Alexander Quayle

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