DNV·GL

ENERGY

LIDAR Assisted Control and Hardware-in-the-Loop Testing using Bladed

Annual European Bladed User Conference 2016

Hamburg, Germany

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LIght Detection And Ranging (LIDAR)

- Remote sensing technology similar to RADAR (**RA**dio **D**etection **A**nd **R**anging) and SONAR (**SO**und **N**avigation **A**nd **R**anging)
- Detection or navigation are referred to locating objects that could be in the air, space, underwater and underground
- Aim is to determine the distance or range of and object where time is crucial
- LIDAR uses light from a laser to image objects like aerosols

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LIDAR types used in wind turbines

- Coherent or direct detection: these systems measure a Doppler shift information
- Achieved by comparing the frequency of the original and the backscattered light
- The Doppler frequency shift gives direct information of the wind speed component along the line-of-sight of the beam.
- Based on the waveform, LIDAR systems can be classified in pulsed or continuous wave
- The estimated wind speed is very useful information to the wind turbine controller

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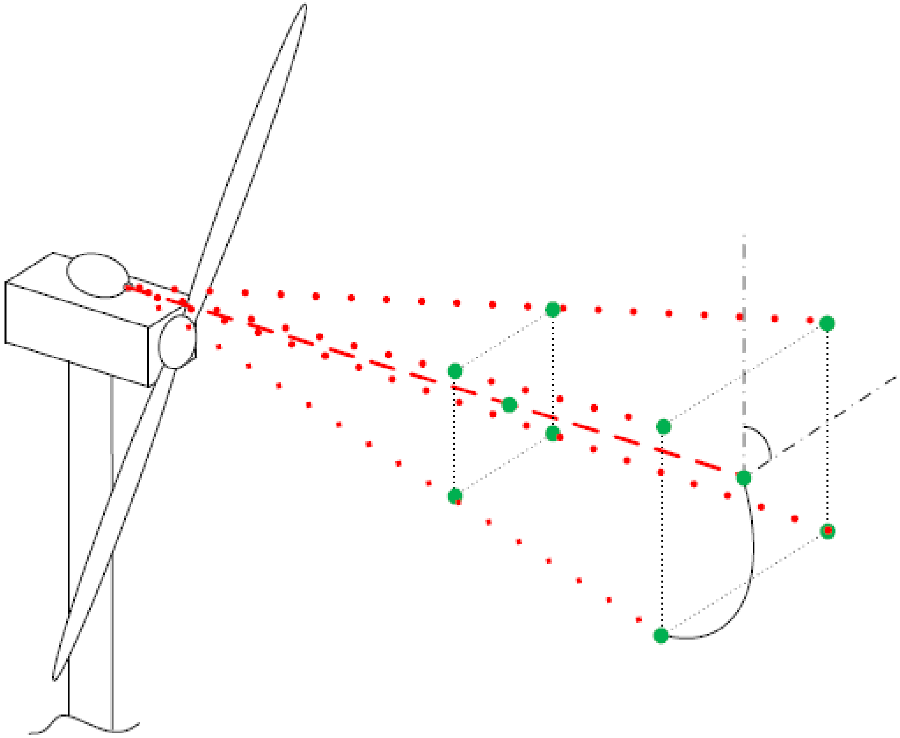
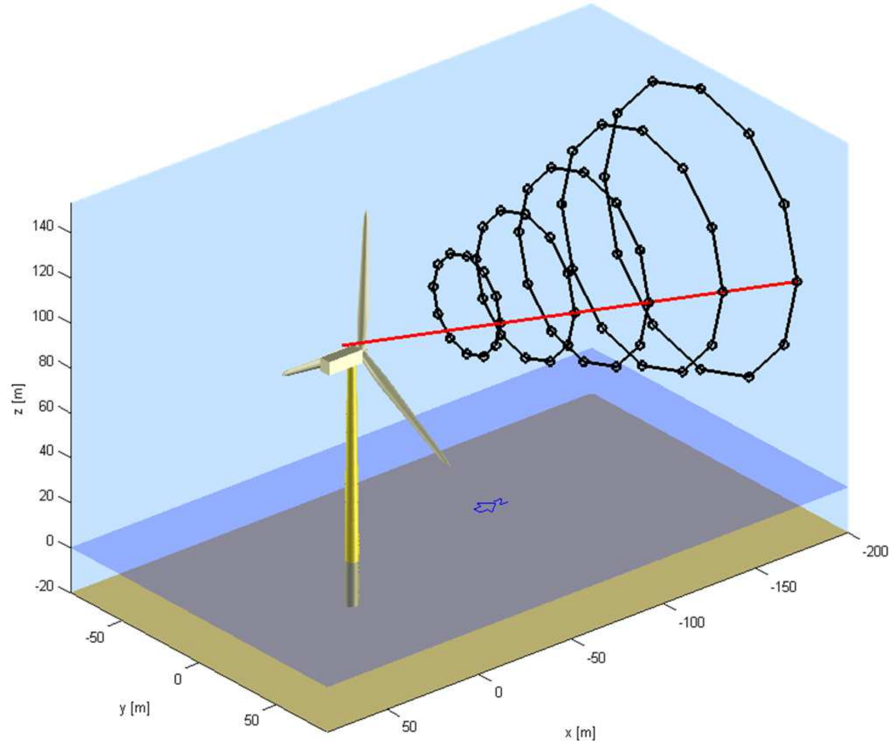
Turbine mounted LIDAR

- Laser Doppler anemometer: Laser beam projected forward from turbine provides advance information about the approaching wind field

Pulsed LIDAR



Continuous Wave LIDAR



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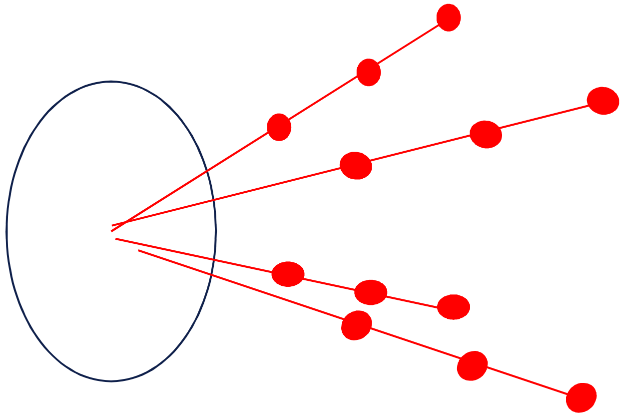
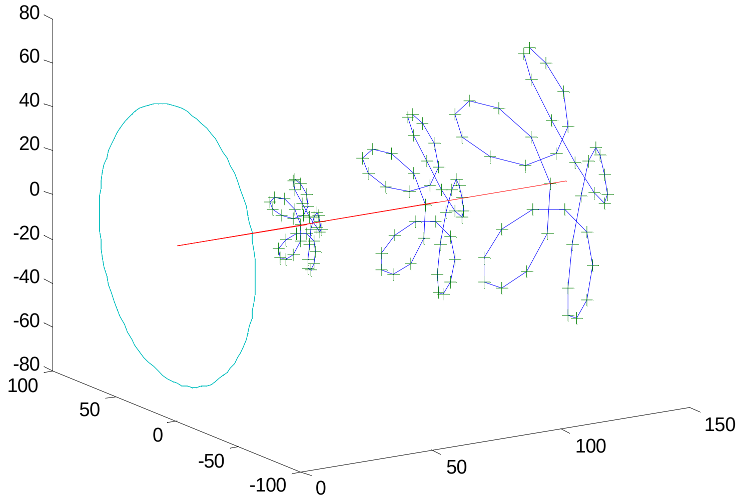
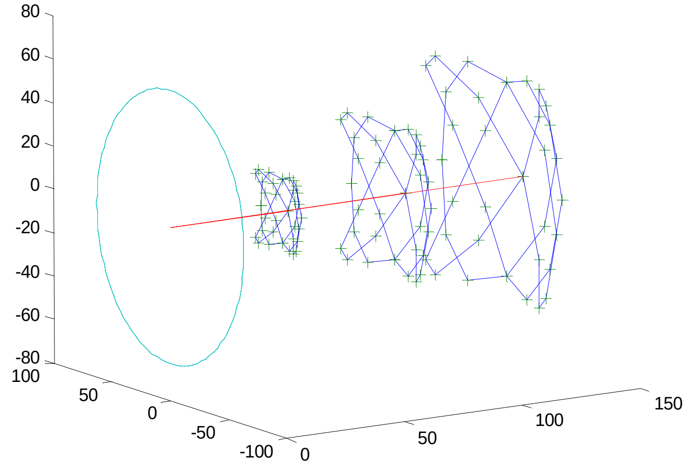
Turbine mounted LIDAR

Scanning patterns:

- Scanning or multiple fixed beams
- Single or multiple distances
- Different figures as scanning patterns







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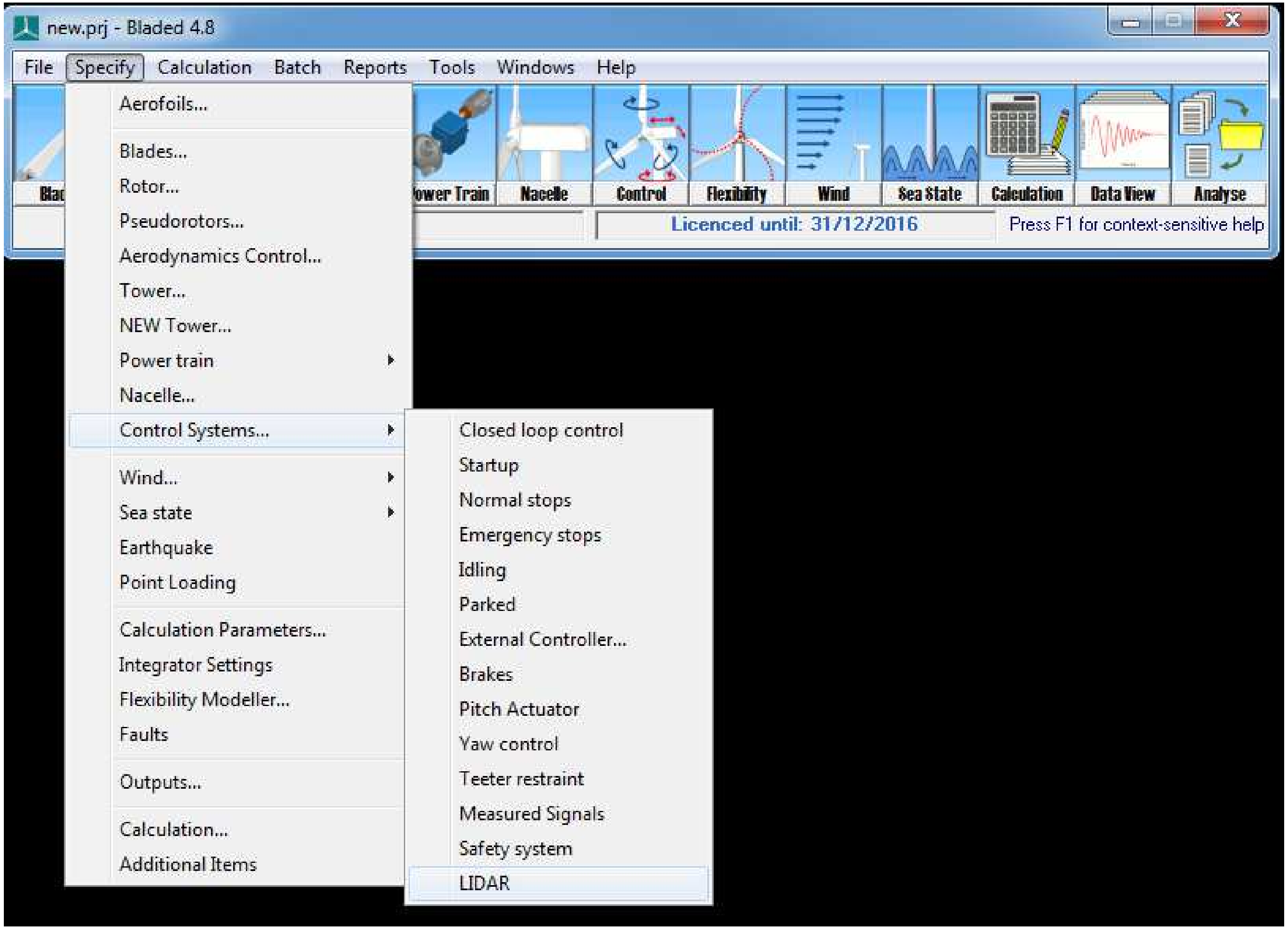
LIDAR modelling in Bladed



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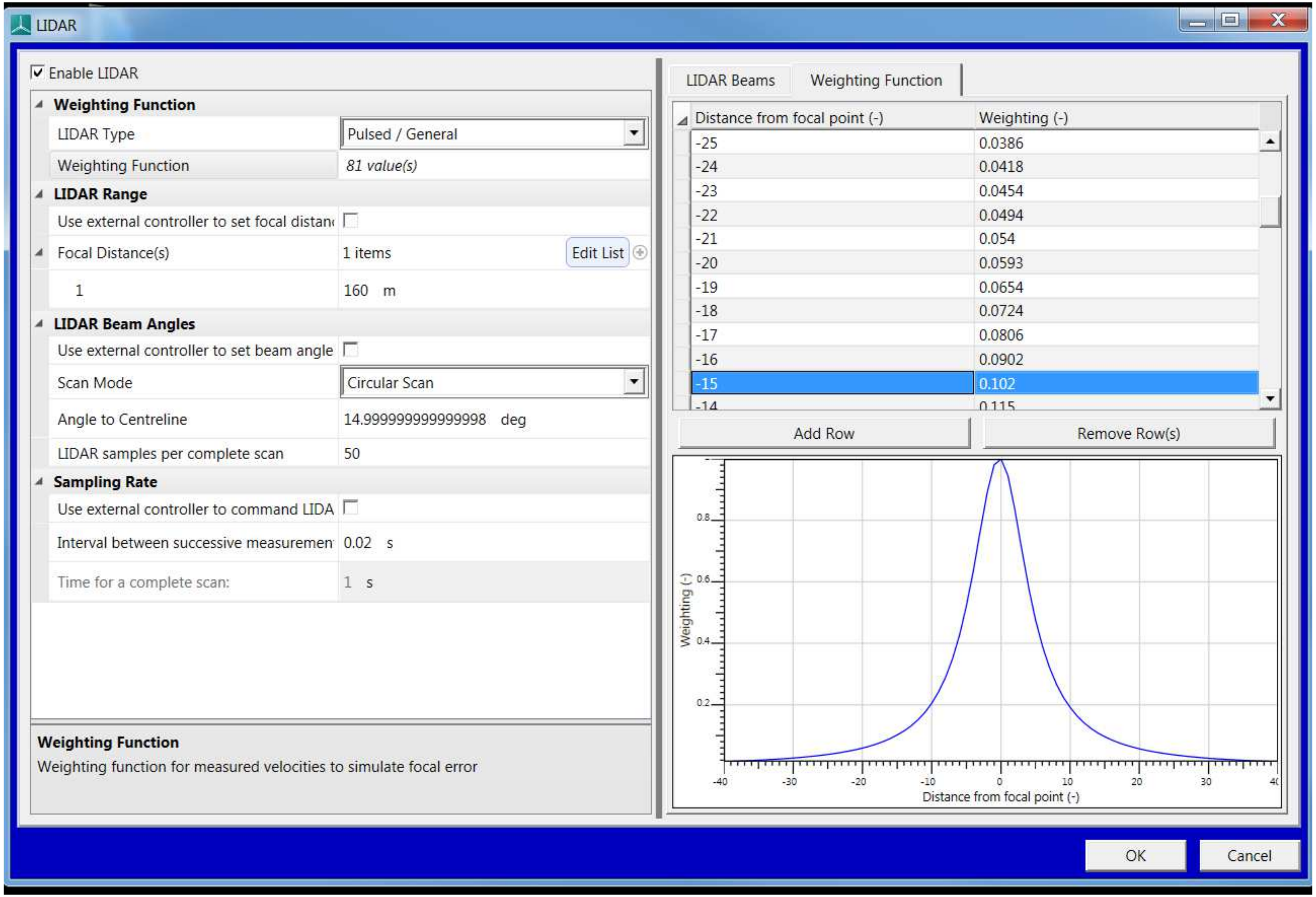
LIDAR modelling in Bladed



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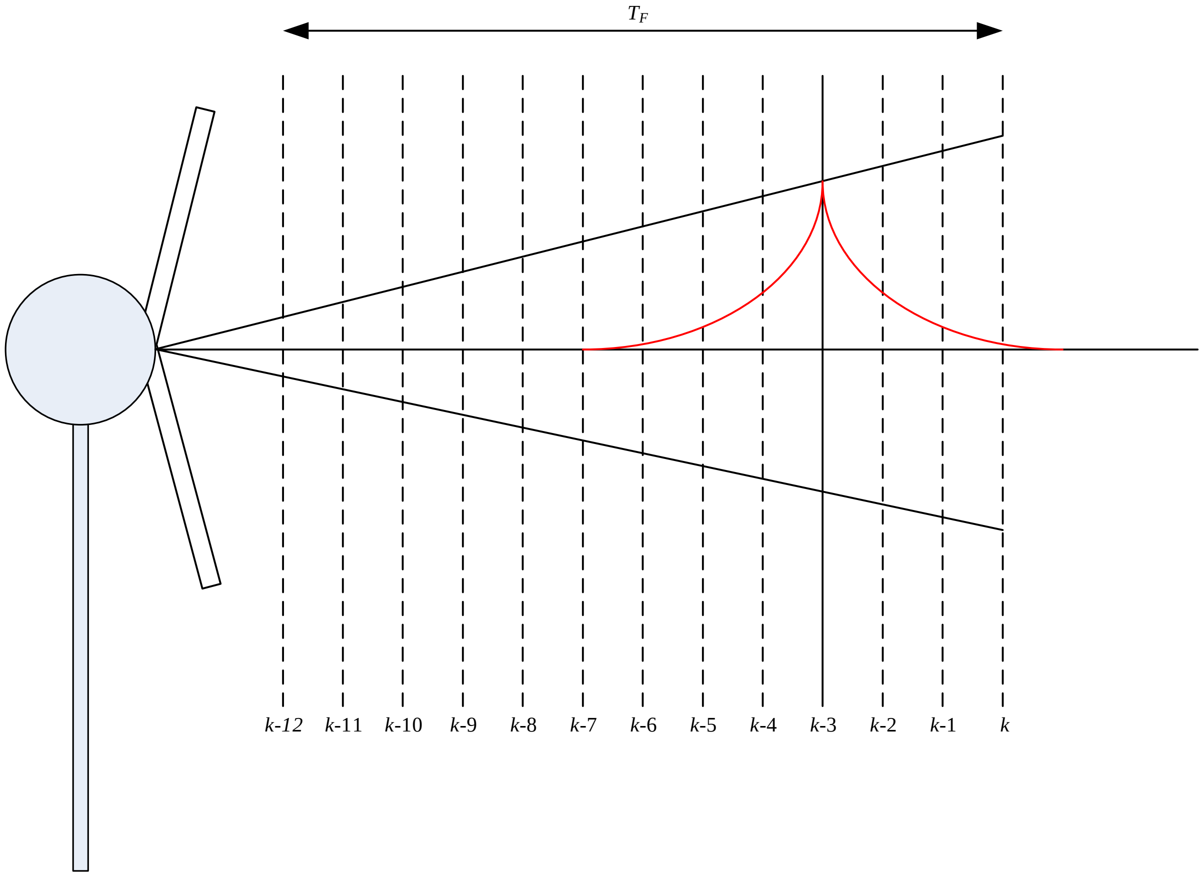
LIDAR modelling in Bladed

The weighting function combines measurements of the wind speed at a range of distances along the beam line to calculate the returned wind speed.



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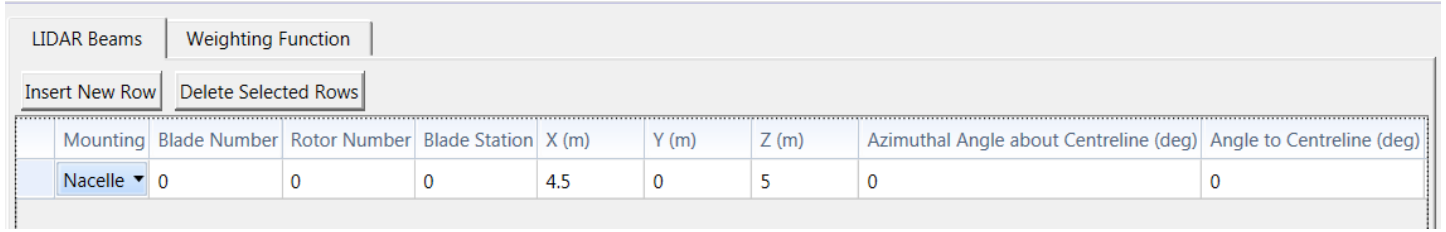
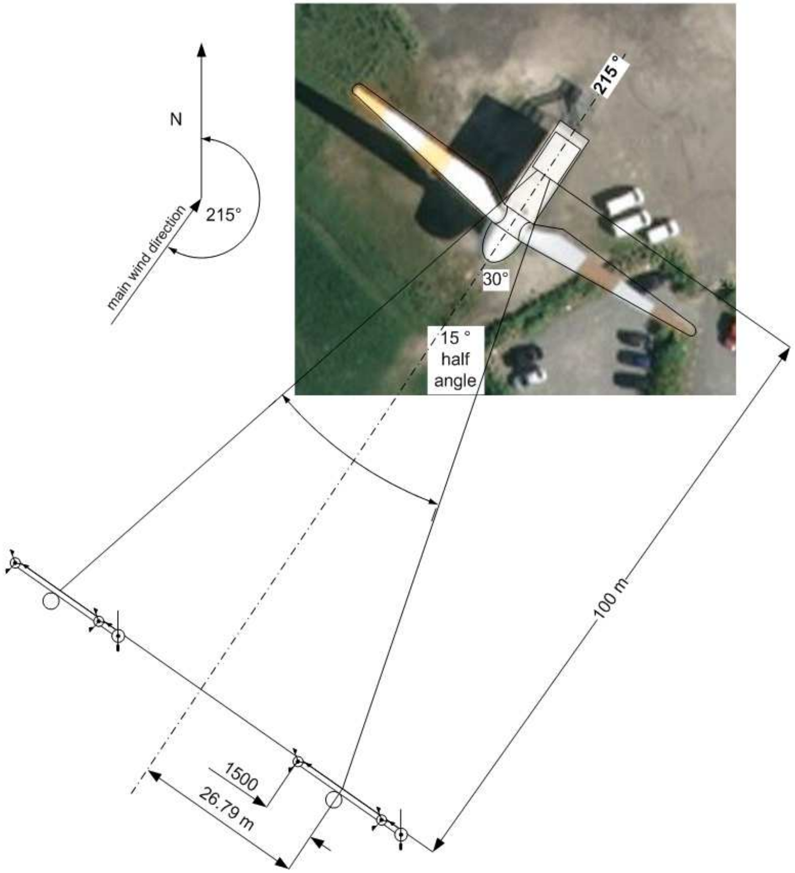
LIDAR modelling in Bladed



LIDAR Beams | Weighting Function

Insert New Row | Delete Selected Rows

Mounting	Blade Number	Rotor Number	Blade Station	X (m)	Y (m)	Z (m)	Azimuthal Angle about Centreline (deg)	Angle to Centreline (deg)
Nacelle	0	0	0	4.5	0	5	0	0



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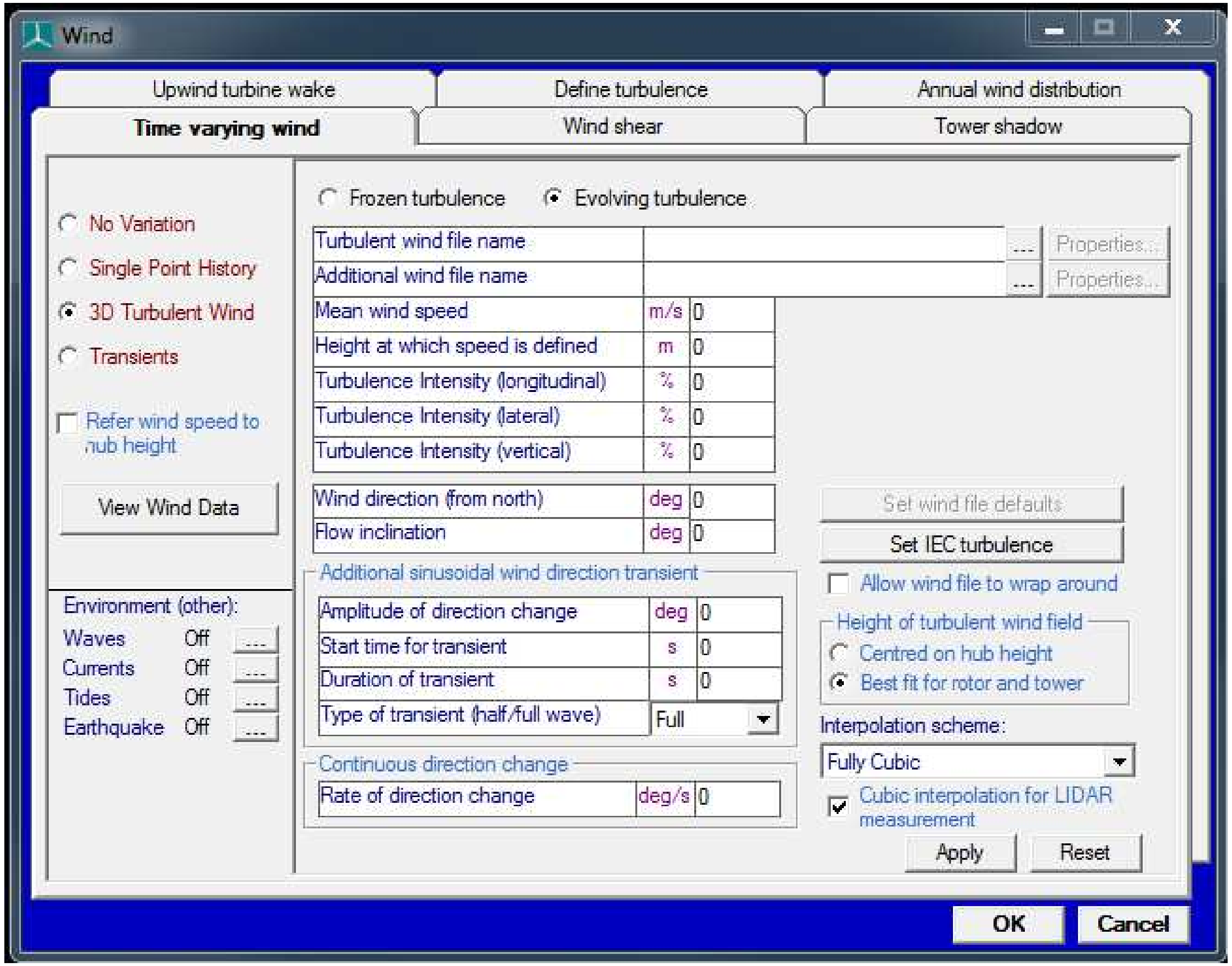
LIDAR modelling in Bladed



Bossanyi, E.A. “Un-freezing the turbulence: improved wind field modelling for investigating Lidar-assisted wind turbine control,” in Proceedings of the European Wind Energy Copenhagen, Denmark, 2012.

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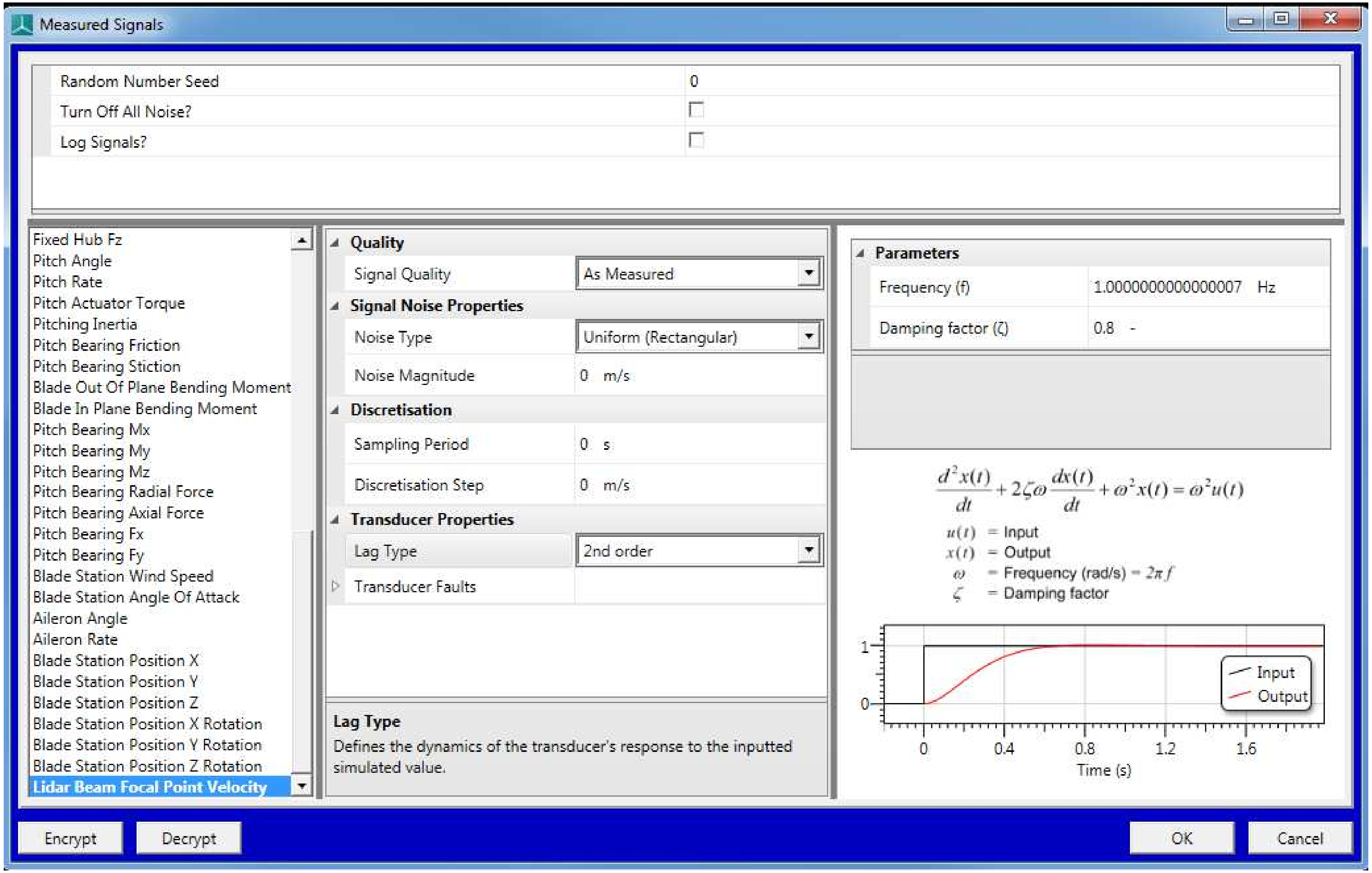
LIDAR modelling in Bladed



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LIDAR modelling capabilities in Bladed: Summary

- Different LIDAR configurations can be simulated
- A LIDAR beam can be emitted from a point fixed to the nacelle or the spinner or the blade.
- Continuous wave or pulsed beams can be modelled
- Multiple beams can be modelled: for example a number of beams pointing in different directions and radial stations
- Simultaneous measurements are possible at multiple focus distances (ranges).
- Scanning or steering of the LIDAR beam(s), and/or changes to the focus distance(s) and timing of samples can be defined by the external controller
- The wind velocity relative to the LIDAR is sampled along the beam line, taking into account any velocities of the LIDAR itself due to motion or structural vibration of the part of the turbine to which it is mounted.
- Around each focus point, the wind velocity is sampled at a number of points along the beam line.
- A weighting function is used for averaging the line-of-sight velocities

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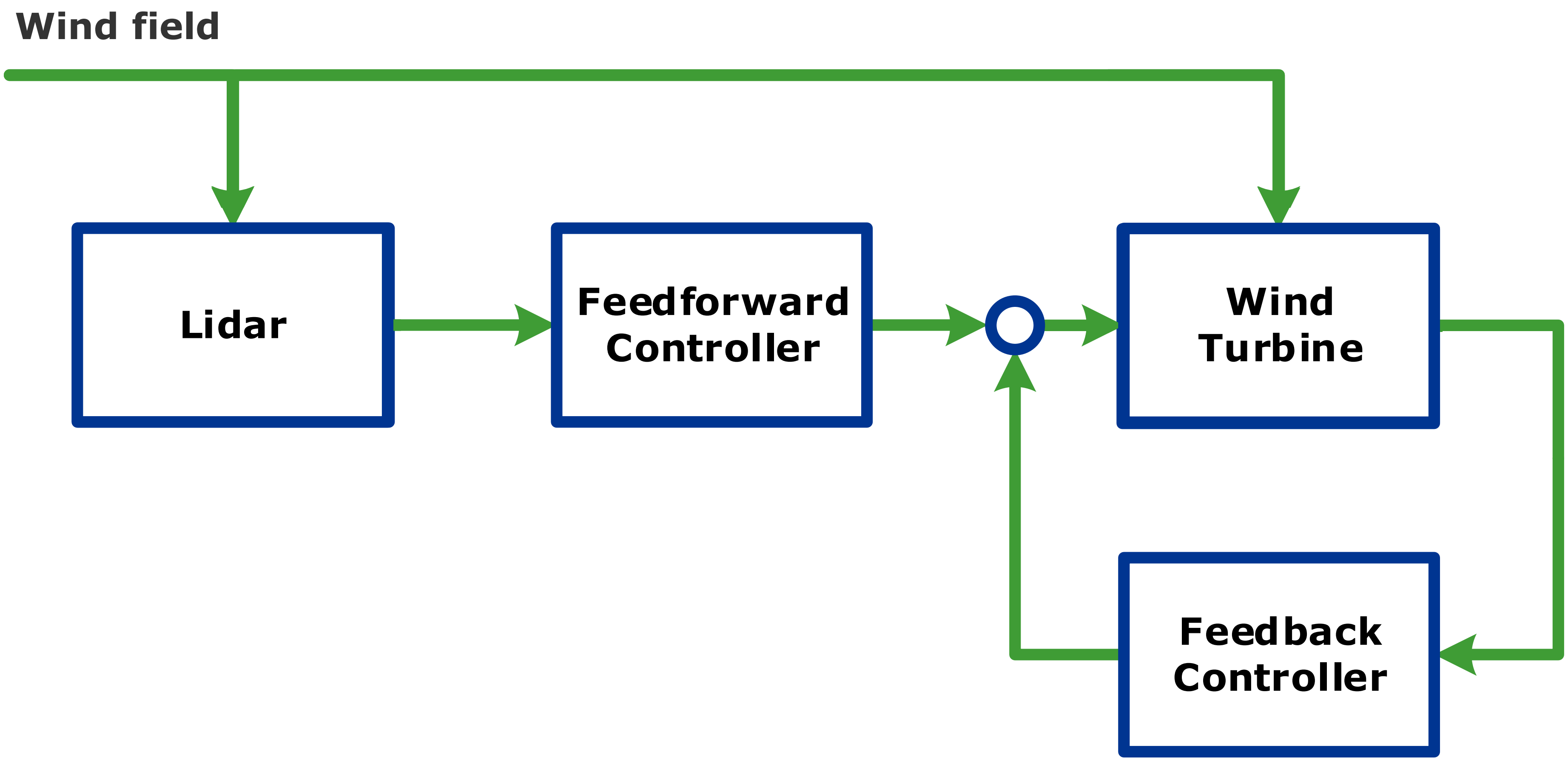
LIDAR Assisted Control



Bossanyi, E. A. Kumar, A. and Hugues-Salas, O. "Wind turbine control applications of turbine-mounted LIDAR" Journal of Physics: Conference Series 555 (2014) 012011

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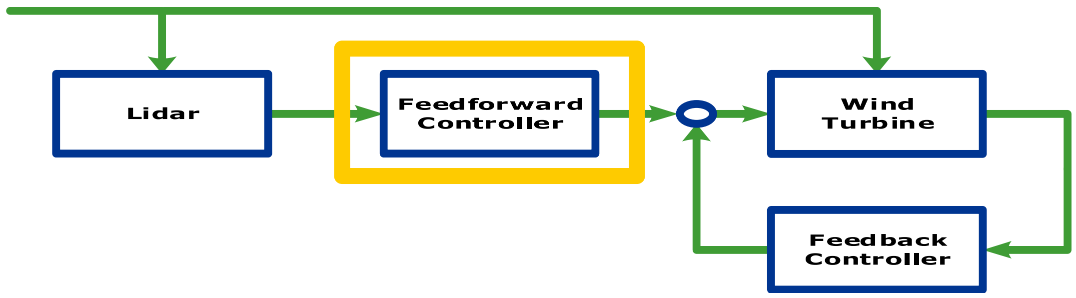
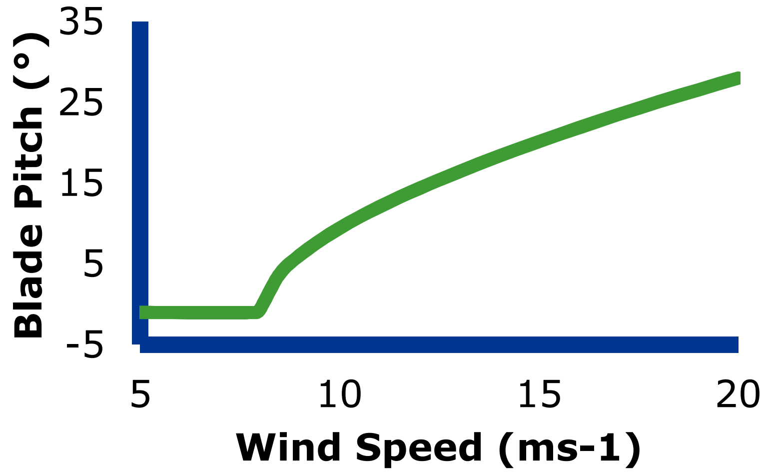
Lidar Assisted Control





$$\dot{\theta}_{FF}(t) = \frac{\hat{\theta}_{ss}(V(t+\tau)) - \hat{\theta}_{ss}(V(t))}{\tau}$$

Feedforward method:

- Take future estimated wind speed from LIDAR and look up for future steady-state pitch angle
- Add pitch rate obtained from the difference between present and future pitch

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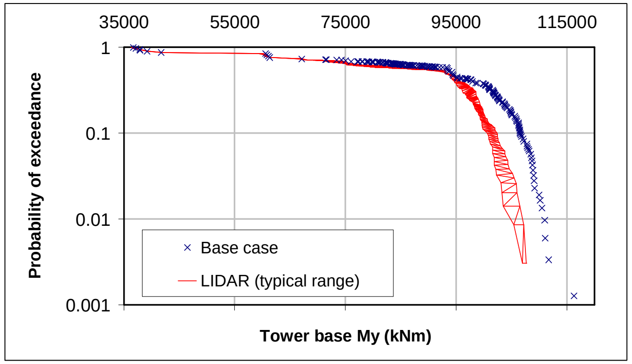
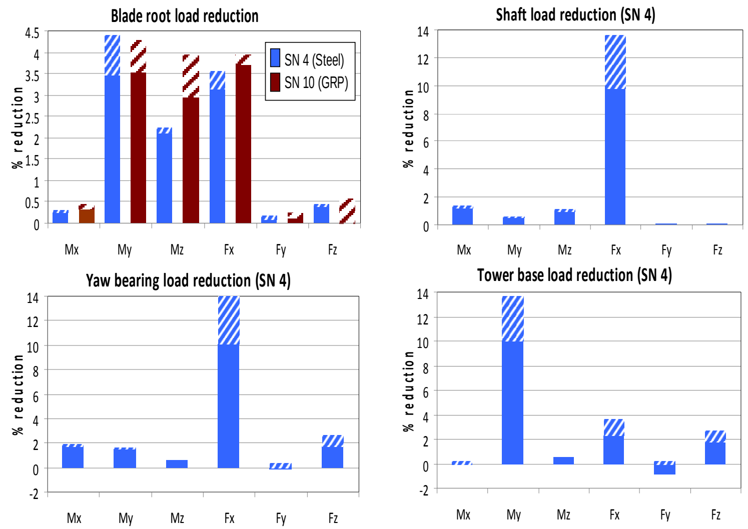
LIDAR Feedforward: Simulation results

NREL 5MW baseline

- 14% tower base lifetime fatigue load reduction
- 8% reduction in tower base extreme

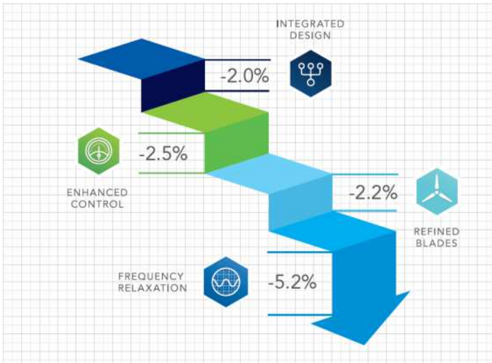




FORCE 7MW baseline *

- 7% lifetime fatigue load reduction in tower base bending moment with Feed Forward Control
- Model Predictive Control (MPC) improves this to 11%

FORCE 7MW LCoE % reductions



* Dobbin, J. et. al., “Fully Integrated Design: Lifetime Cost of Energy Reduction for Offshore Wind” Proceedings of the Twenty-fourth, International Ocean and Polar Engineering Conference, 2014, vol. 3, pp. 415–423.

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Field test results at NREL with five-beam LIDAR

- A field-testing campaign to test LIDAR Assisted Control (LAC) has been undertaken on a 600-kW turbine using a fixed, five-beam LIDAR system.
- The campaign compared the performance of a baseline controller to four LACs with progressively lower levels of feedback using 35 hours of collected data.

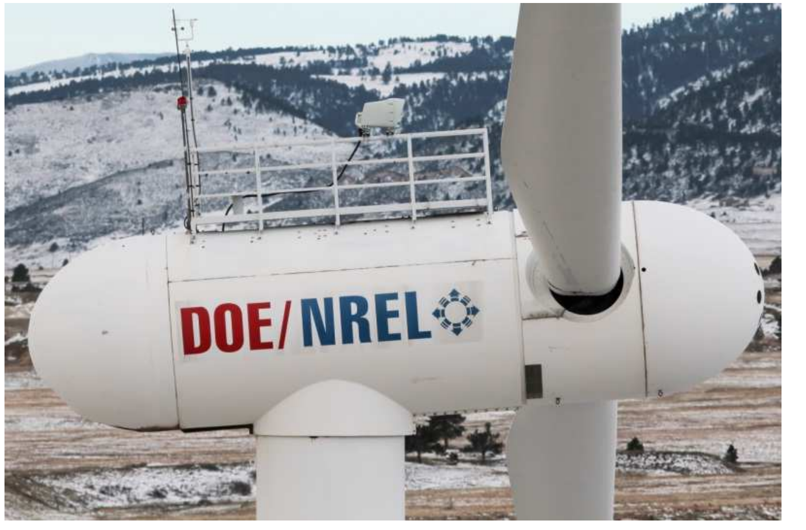


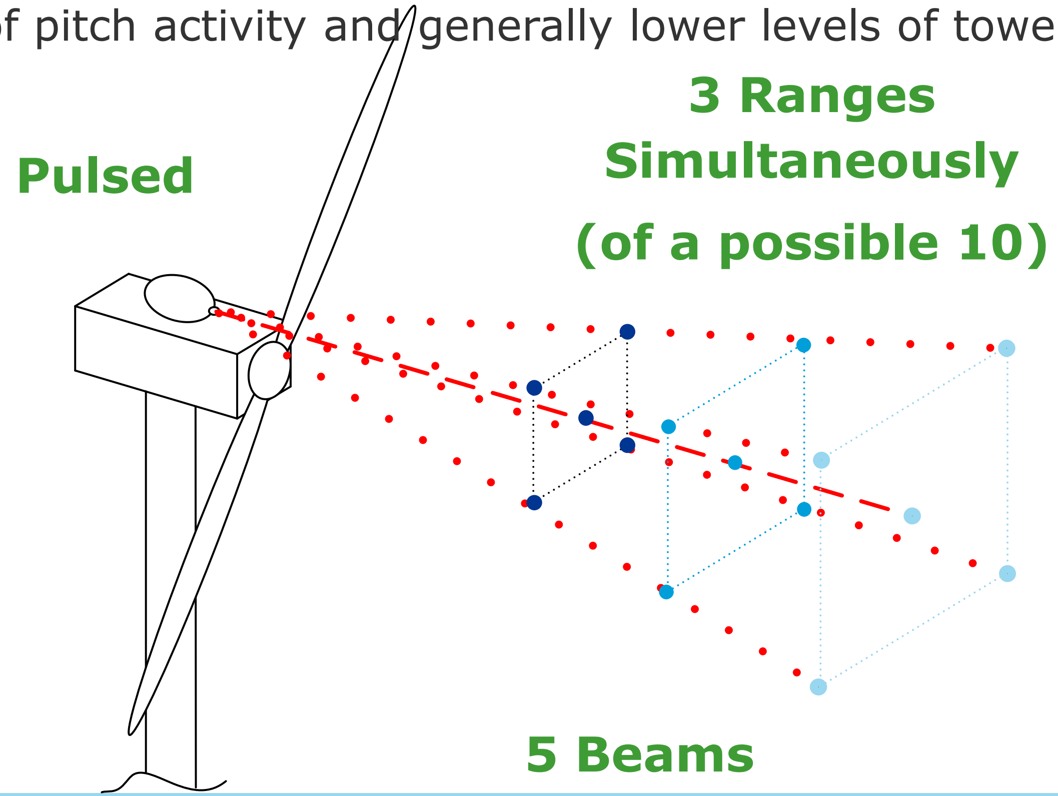
Photo Credit: Lee Jay Fingersh, NREL 33621

Kumar at al. “Field testing of LIDAR assisted feedforward control algorithms for improved speed control and fatigue load reduction on a 600kw wind turbine”, EWEA Paris, France, November 2015.

Bossanyi, EA et al., “Wind turbine control applications of turbine-mounted LIDAR,” Proc. Torque From Wind conference, Oldenburg, Germany, 2012.

Field test results at NREL with five-beam LIDAR

- Collected data shows that utilising measurements from multiple range gates on a pulsed LIDAR system can result in rotor averaged wind speed (RAWS) estimates with greater levels of correlation with wind speed at the rotor than using a single range gate.
- The LACs showed higher levels of speed control performance with significantly reduced levels of pitch activity and generally lower levels of tower excitation.



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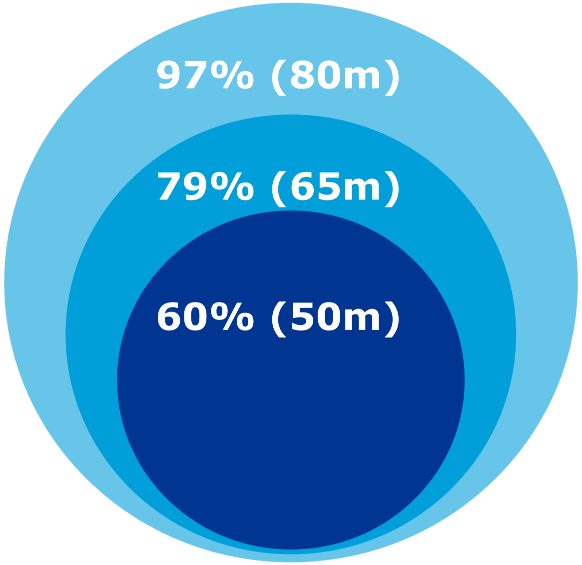
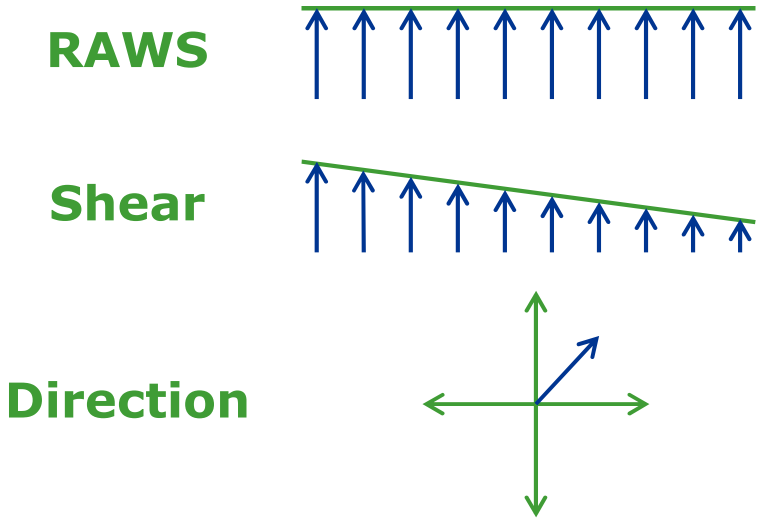
Field test results at NREL with five-beam LIDAR

- The feedforward control algorithm makes use of the RAWS data from three range gates focused at 50, 65 and 80m.
- These gates correspond to covering the centre and approximately 63%-100% of the rotor radius using a beam angle of 15° from horizontal.
- The LIDAR processes the line-of-sight data to return the current RAWS, wind shear and wind direction estimate for each range gate.





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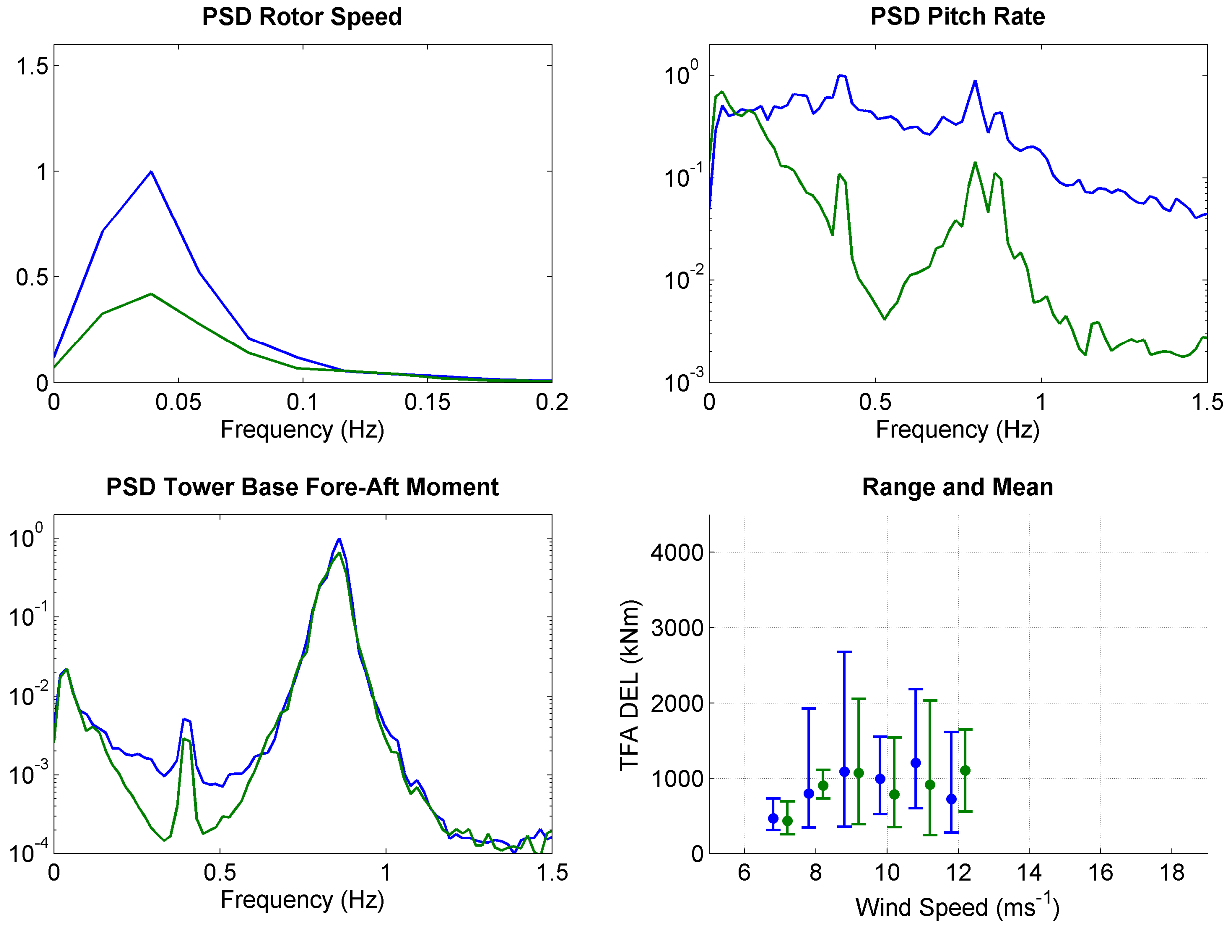
Field test results: 38% Controller Gain



Test with (green) and without (blue) Lidar assisted control with full pitch-speed controller gain

Speed control improvement
Further reduction in pitching above 0.2Hz
Further reductions in tower spectral response/DEL, 1P

- LAC easily added to existing controllers
  - Relatively low levels of tuning for immediate performance increase
  - No impact on stability
- LAC achieved better speed regulation than feedback only
- Detuning resulted in:
  - Reduced pitch activity
  - Reduced tower spectral response
  - Reduced tower fatigue

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Bladed Hardware Test Module

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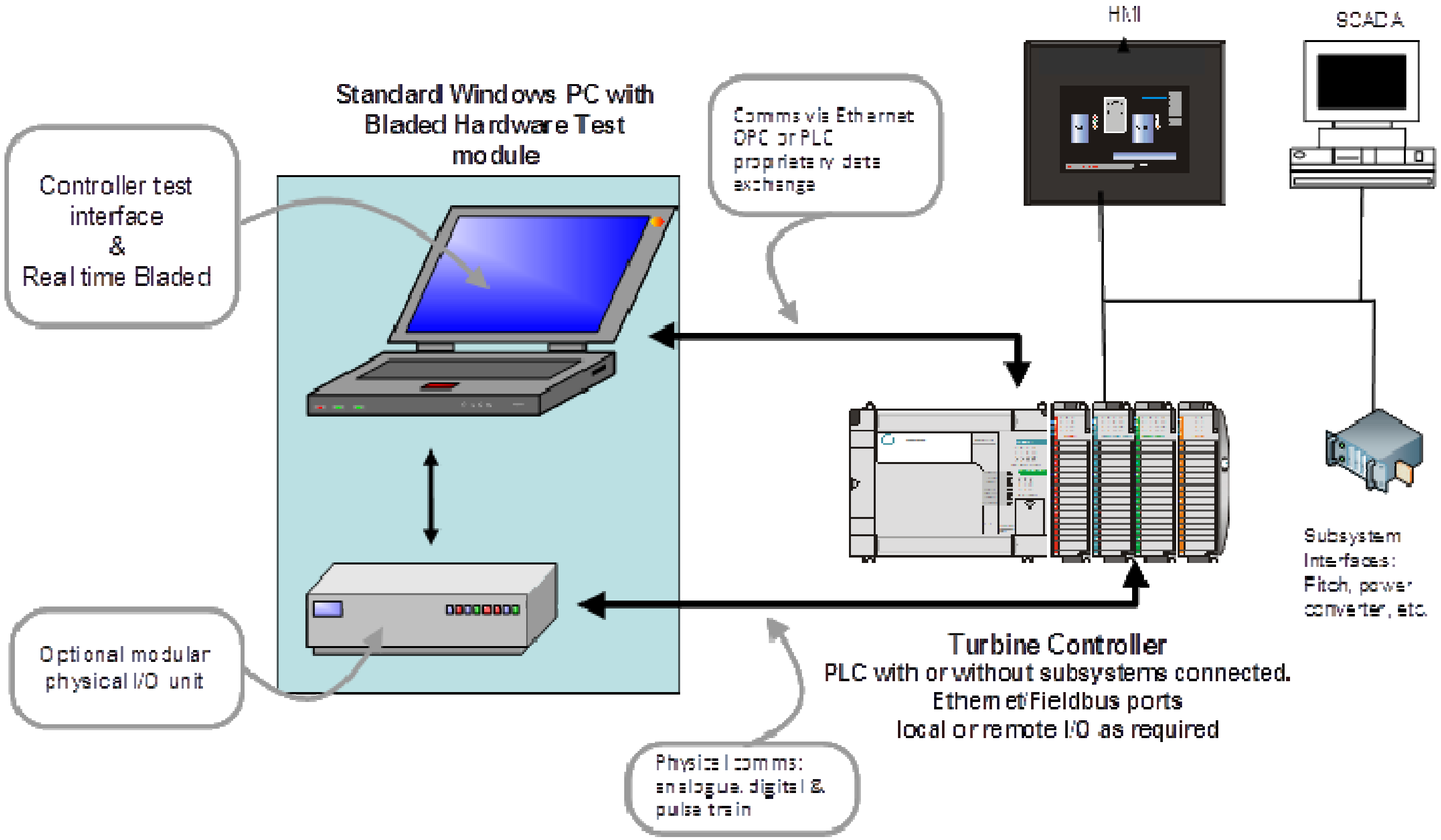
Bladed Hardware Test Module (BHTM)

- Connects several devices (software or hardware) together and pass information between those devices
- Defines test procedures composed by sequential instructions
- Contains a .NET C# scripting environment for coding in hand-written logic



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Bladed Hardware Test Module (BHTM)

- Transforms the Bladed design simulation to a real-time hardware-in-the-loop simulation
- Use the same turbine model developed in turbine design and load calculations
- Customise the Bladed simulation to model complex behaviour
- Flexibly connect turbine hardware to the simulation
- Versatile set of input/output modules easily added to the simulation
- Test scripting system to manipulate the simulated environment and evaluate pass/fail results
- Hardware in the loop tests can reduce the risk of failures, delays and expensive rework in commissioning and actual turbine use, can improve confidence in the turbine product and could help with procurement decisions.

Thank you!

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