TotalControl

Workshop

Online, 10th December 2020

Work Package 3: Turbine controller enhancements

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of the European Union

Task 3.1 (completed)

develops new turbine controller features of relevance in the context of wind farm control, and uses simulation modelling to test and evaluate them.

- Based on Samsung 7MW demonstration wind turbine (ORE Catapult, Levenmouth).
- Aeroelastic model developed and reference loadset generated.
- Active power control for grid ancillary services: Virtual Synchronous Machine concept for inverter control
- Active tower damping – offshore
- Power set-point reduction algorithms*
- Model predictive controller*
- LiDAR-assisted control for load reduction*
- Individual pitch control using tower-top sensors*

**For field tests in Task 3.2*

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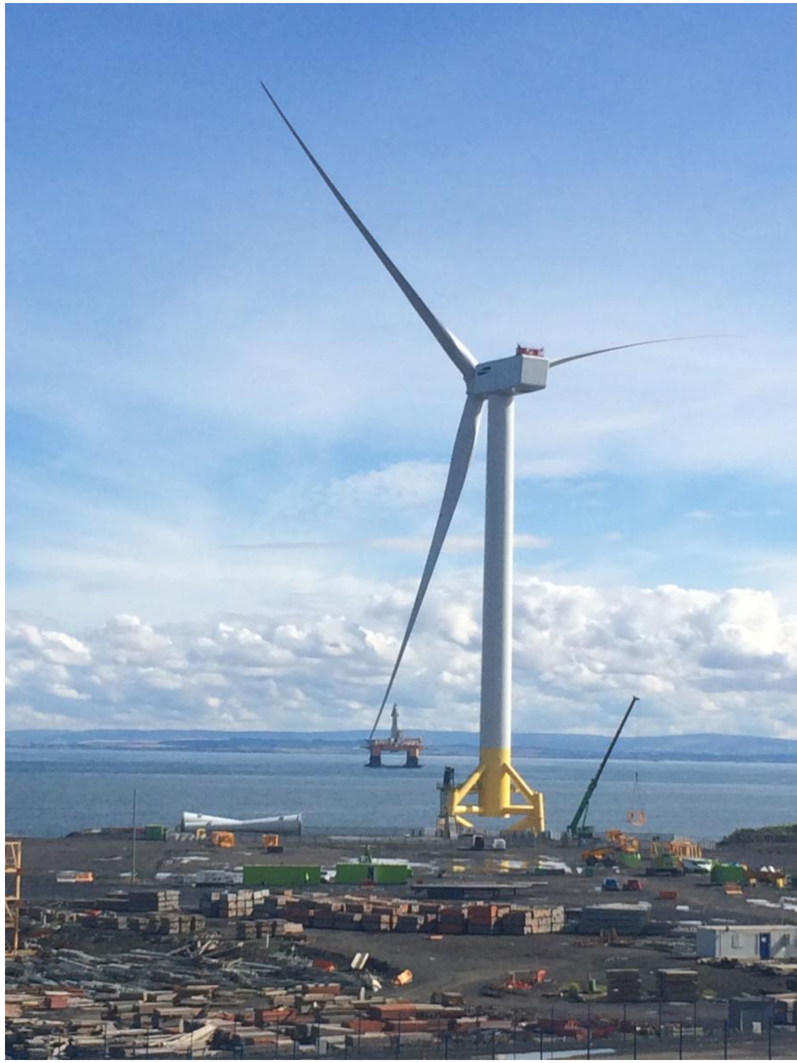
Task 3.2

implements some controller enhancements on the 7MW turbine at Levenmouth and evaluates their performance in the field.

- Forward-facing scanning LiDAR to measures the inflow
- Rear-facing LiDAR to measure effects on the wakes
- Flow model for induction zone (LiDAR+CFD)
- Yaw misalignment tests
- Power reduction tests
- IPC tests
- LiDAR-assisted control tests
- Delta control tests
- Fast frequency response tests
- Model predictive control implementation



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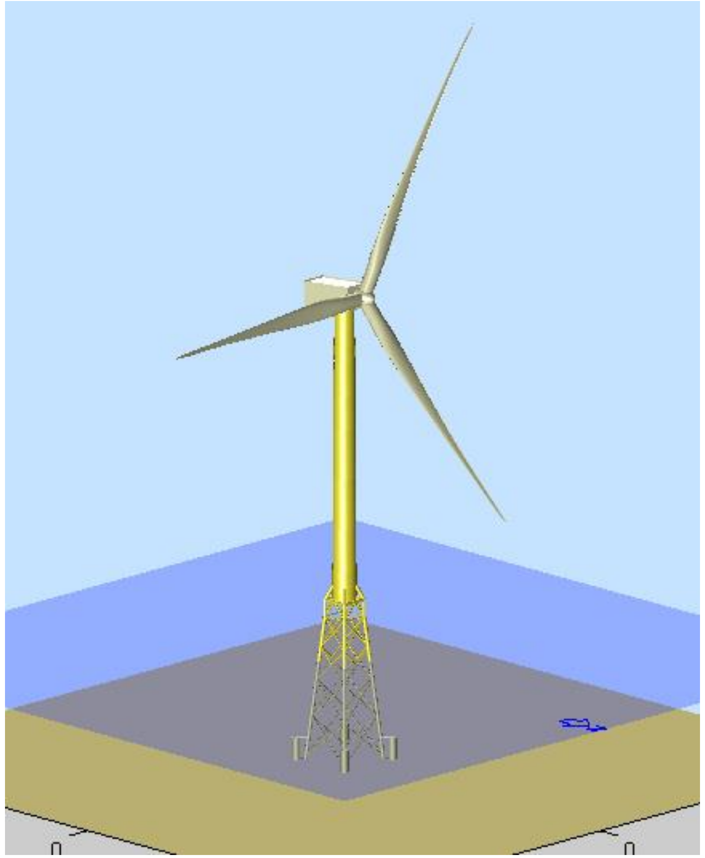
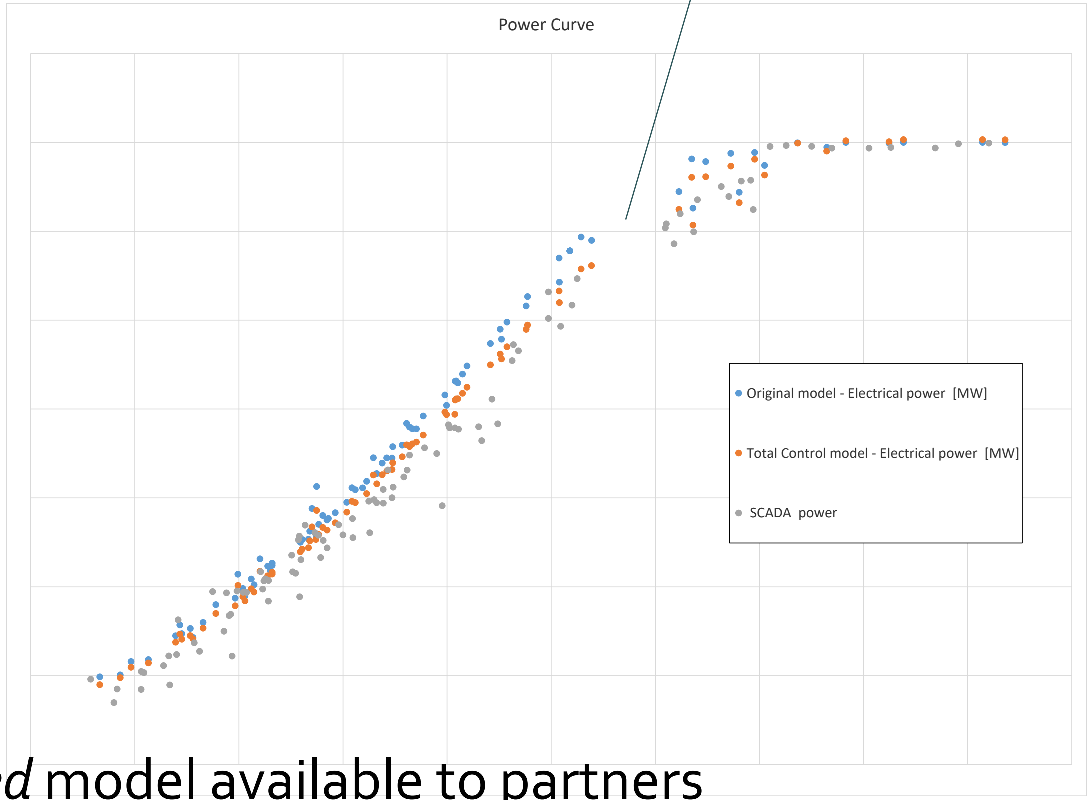
7MW model & loads

(Deliverable D3.1, OREC)



Updated *Bladed* model matches real power performance



- *Bladed* model available to partners
- Reference loadset calculated & available to partners

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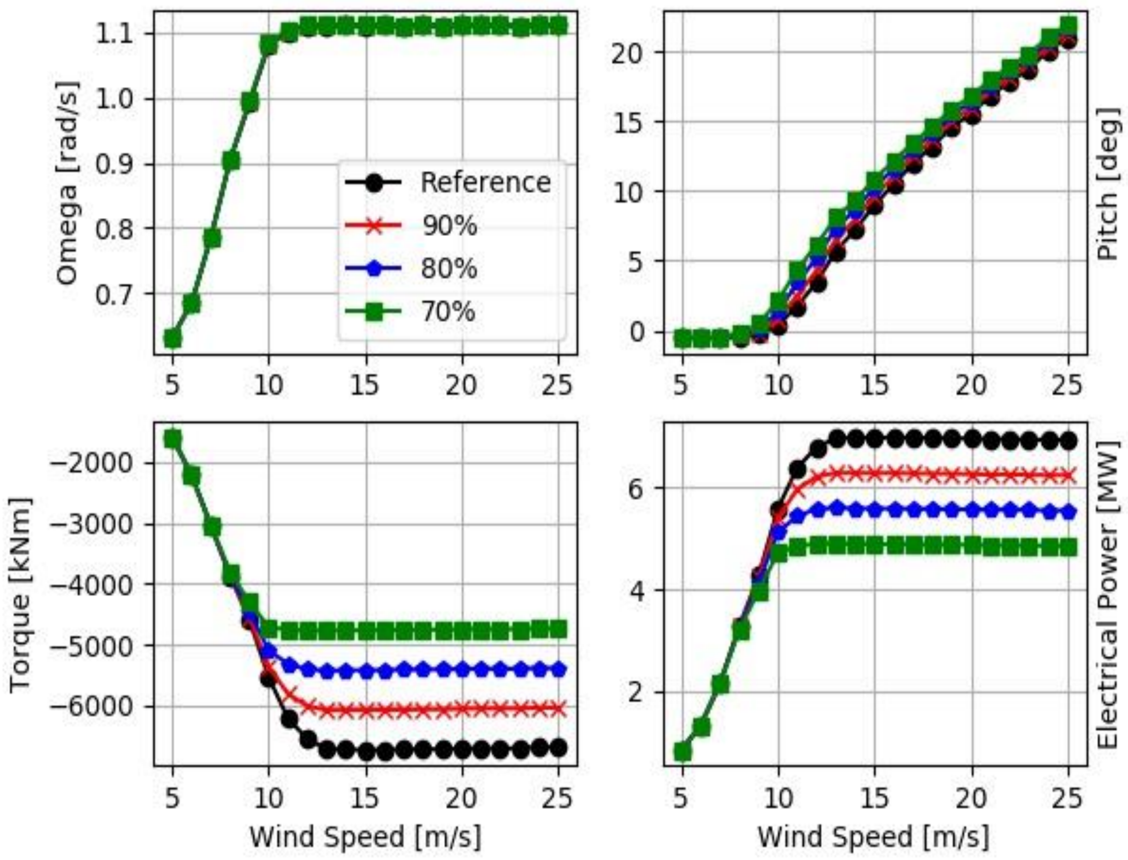
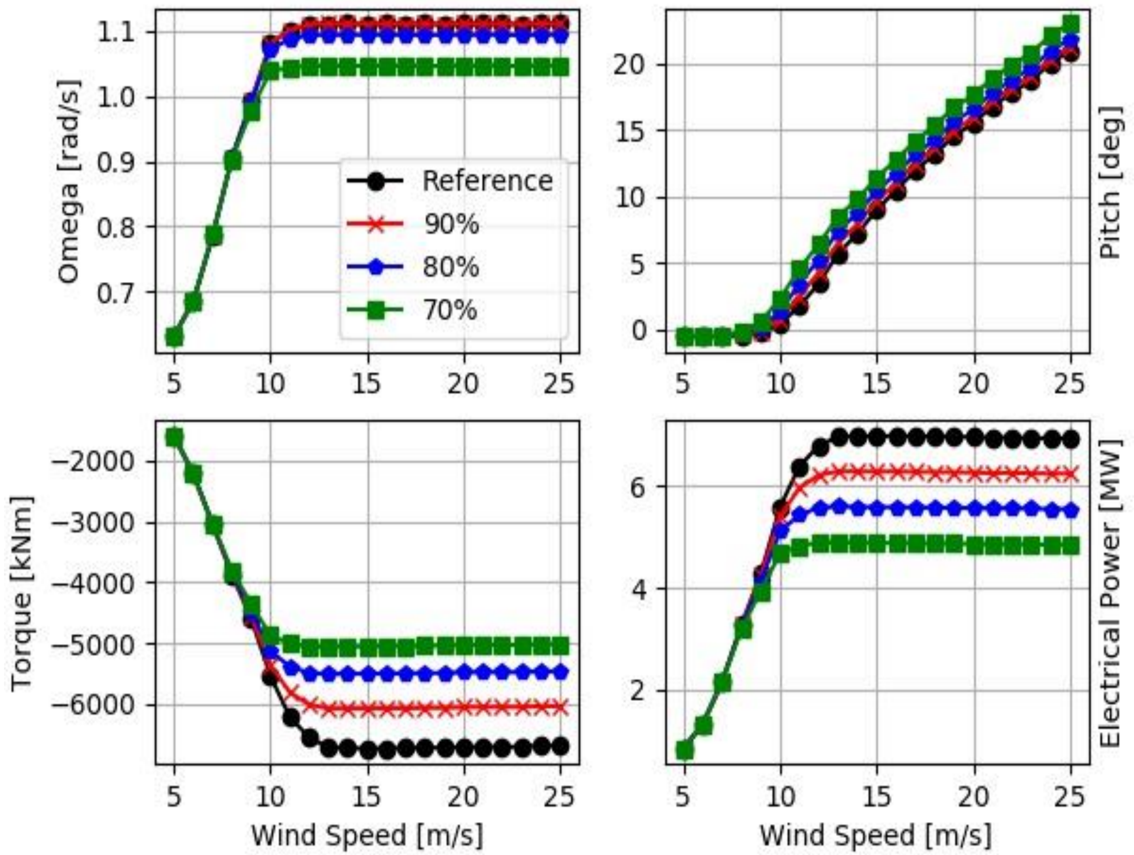
Down-regulation (Deliverable D3.2, DTU)

Maintaining rated rotor speed



With decreasing rotor speed



Different effects on turbine loads

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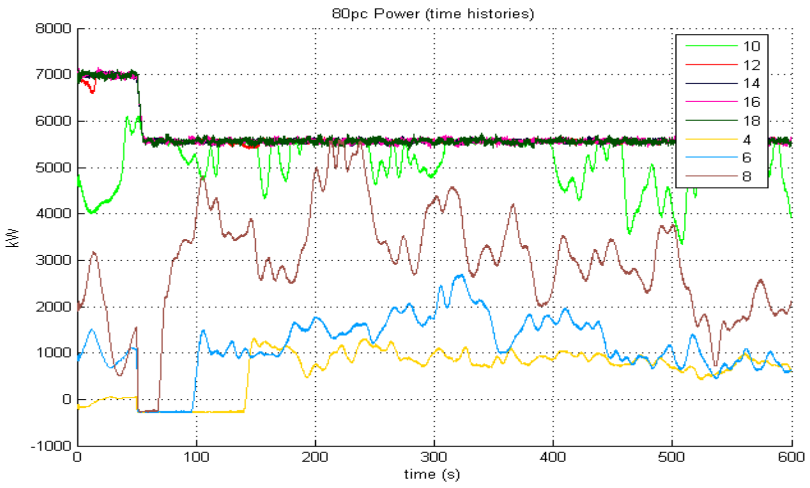
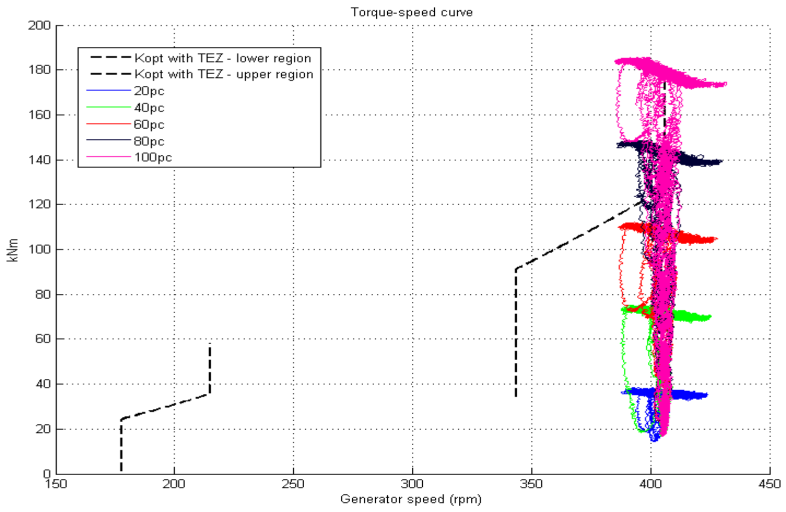
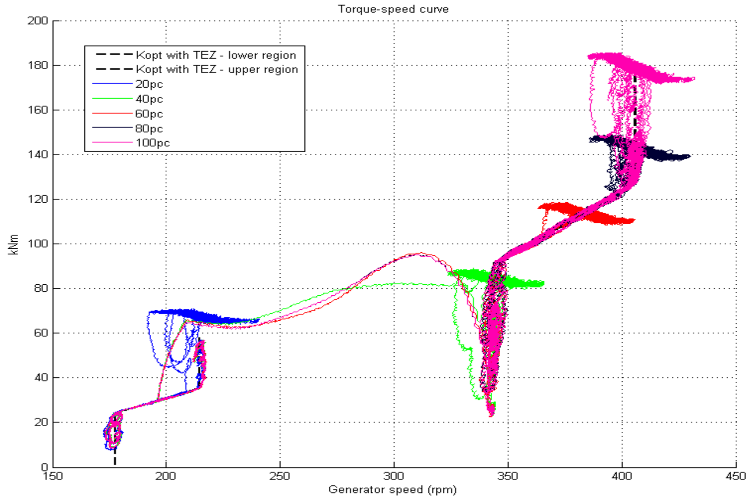
Down-regulation (Deliverable D3.2, DNV GL)

Implementation in full turbine controller: Bladed simulations







Important to consider the speed exclusion zone!

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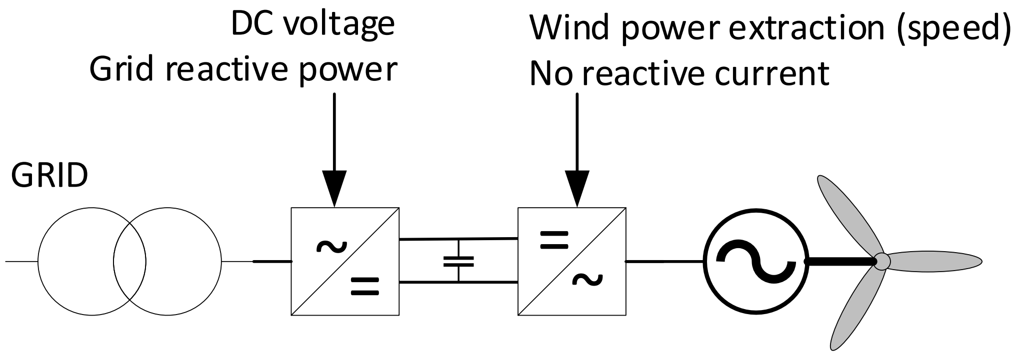
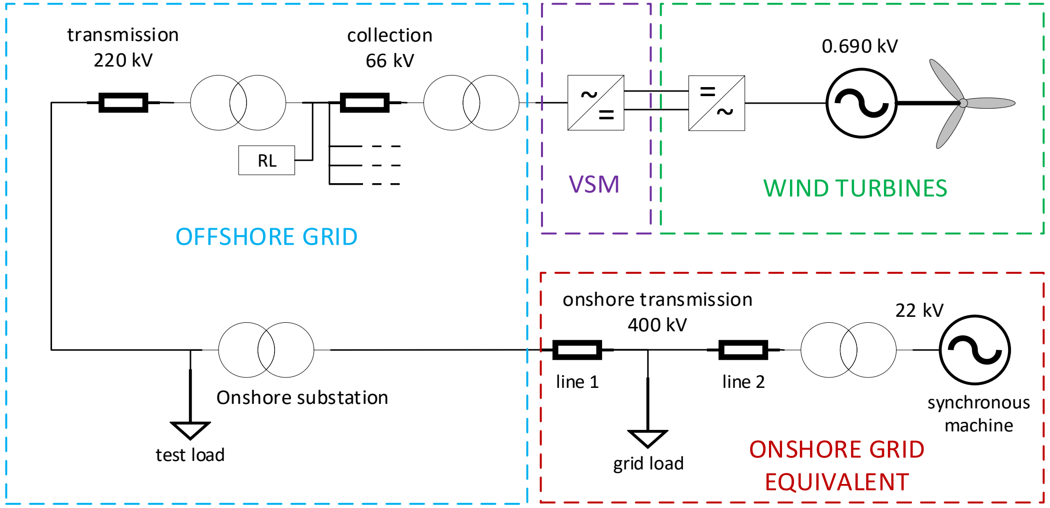
Virtual Synchronous Machine (VSM)

Fast frequency response through modifications to the wind turbine converter control system (Deliverable D3.2, SINTEF)





Simulation model

Scheme 1: VSM converter controlling DC voltage - energy drawn only from DC-link capacitor

Scheme 2: VSM converter controlling active power - wind turbine inertia can also contribute, giving greater capability

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Active damping of tower loads for offshore turbines

Deliverable D3.3 (SINTEF)

- Top-down controller design using high-resolution model (~300 states)
- Can we steer the direction of tower oscillation, to control how much fatigue is accumulated at different points around the tower circumference?
  - ➢ Yes, but no particular advantage identified
- Can we control generator torque and/or blade pitch to provide effective damping and rejection of ocean wave loads when the turbine is idling?
  - ➢ Yes, need different strategies, including changing the yaw direction, depending on wind/wave misalignment, rotor speed, wind speed and wind variability.

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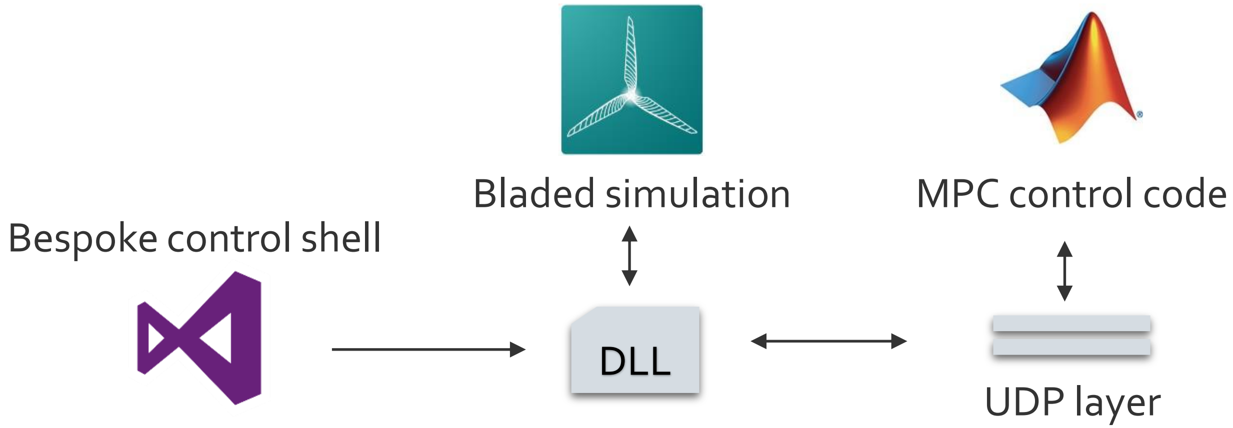
Model predictive turbine control

Deliverable D3.4 (DNV GL)



- Using Bladed to generate linear models
- Closing the loop before posing the optimisation problem
- Reducing model order of closed-loop model
- Communicate over UDP to allow Matlab to talk to Bladed simulations
- Good success with turbulent and deterministic tests
- Handles the transition around rated wind speed
- Method developed with a 2MW generic turbine, then applied directly to Samsung 7MW without any tuning

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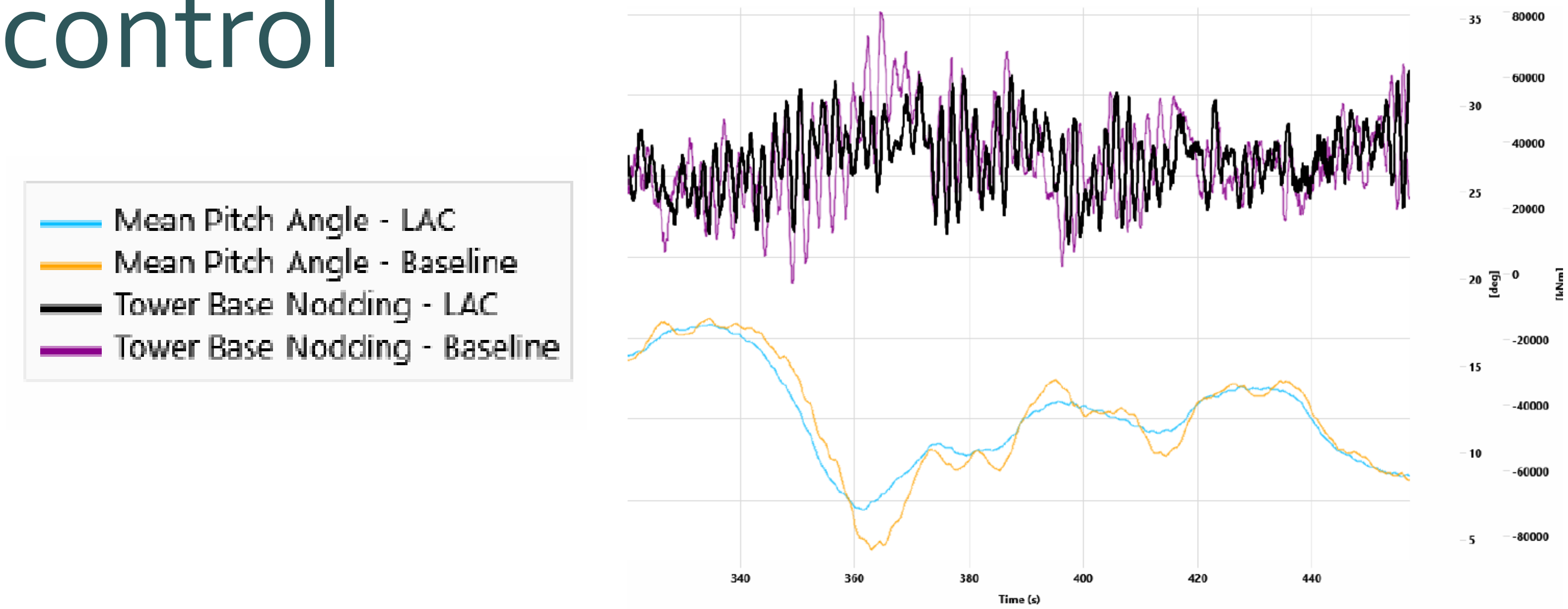
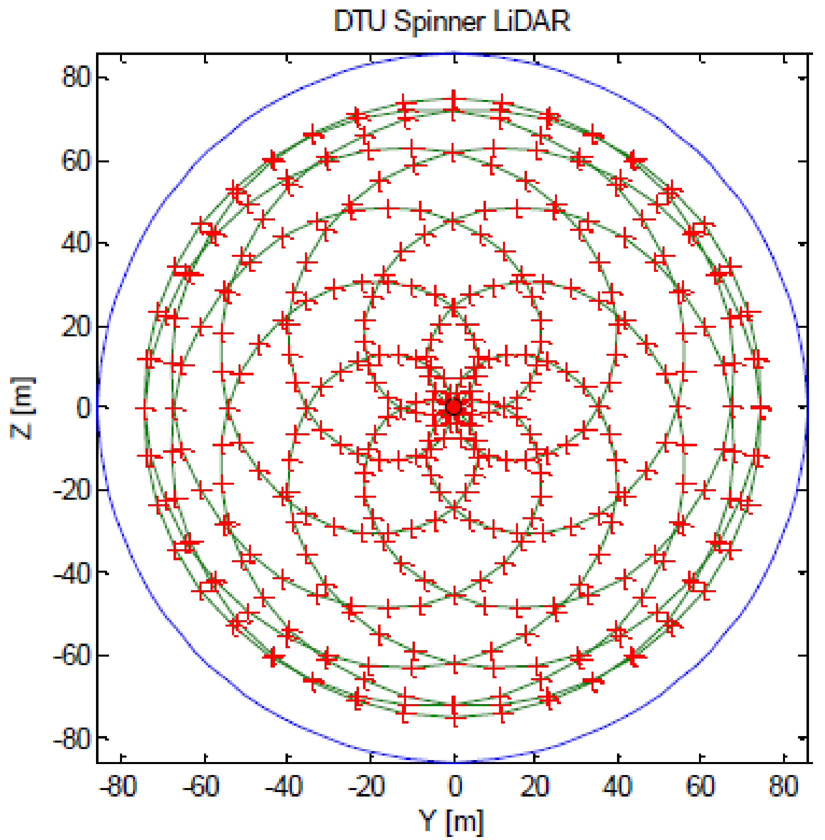
LiDAR-assisted control

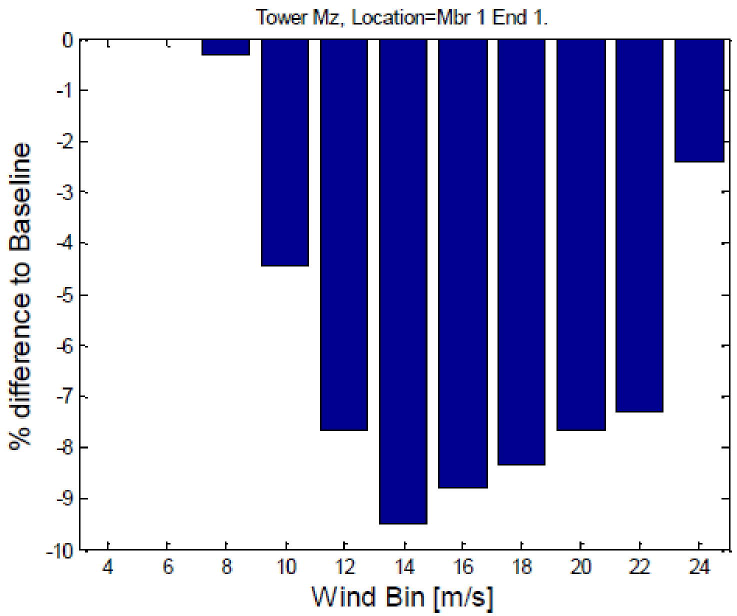
Deliverable D3.5 (DNV GL)

BLADED simulations





LiDAR scanning pattern

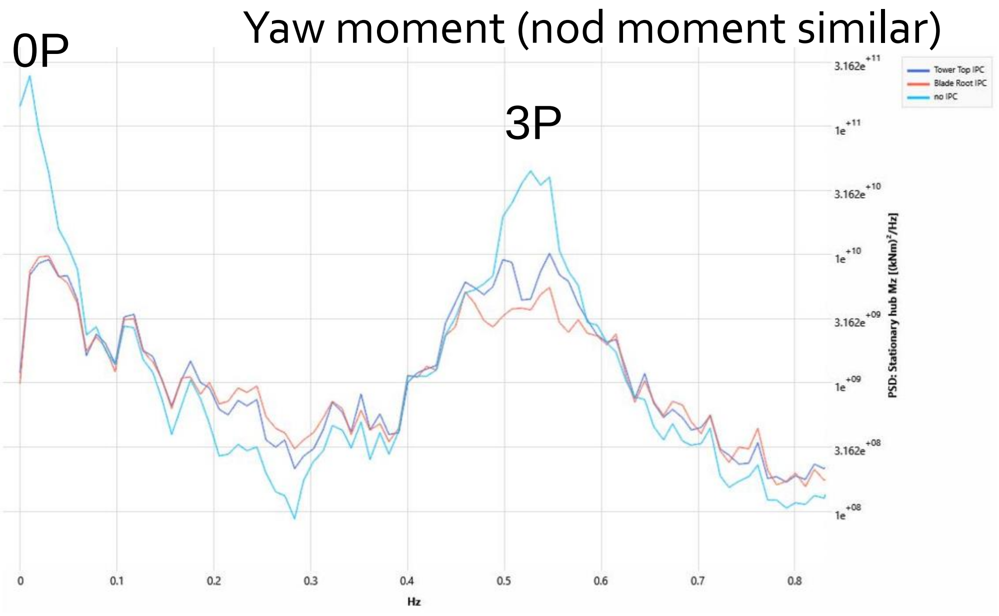


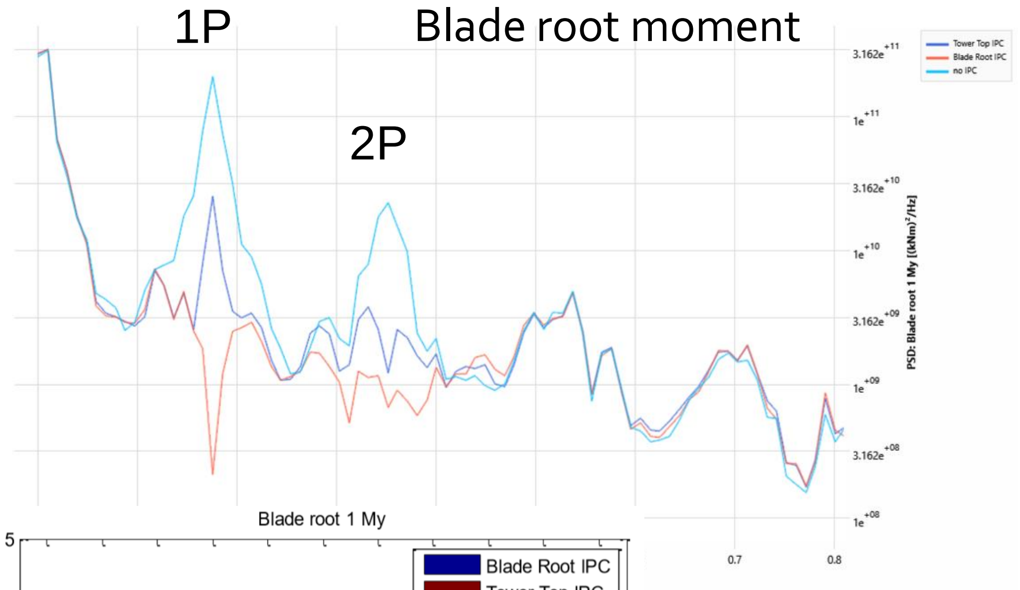
Tower base fatigue load reduction vs wind speed

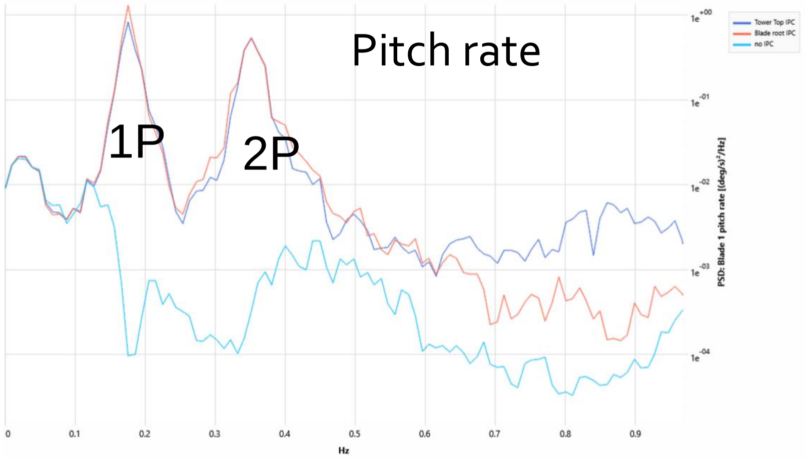
Individual Pitch Control

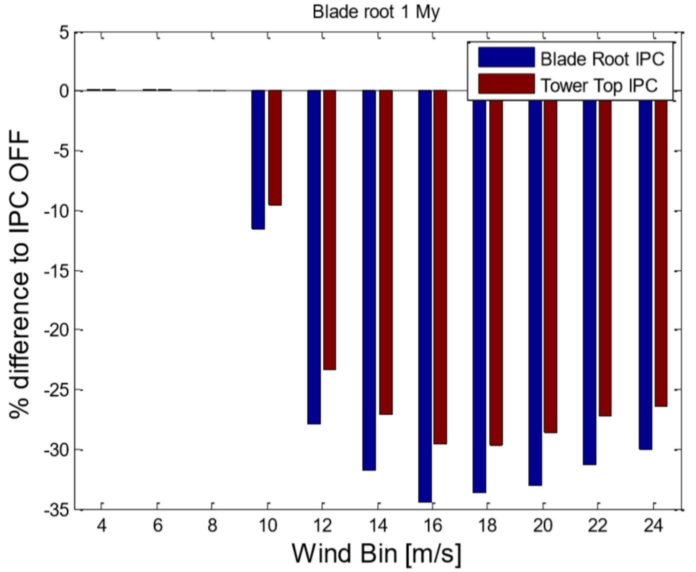
Deliverable D3.5 (DNV GL)

1P & 2P IPC; Blade root or tower top sensors vs no IPC

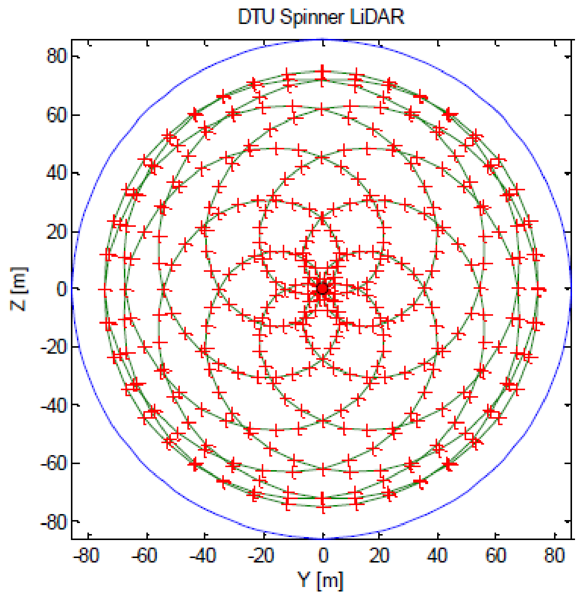






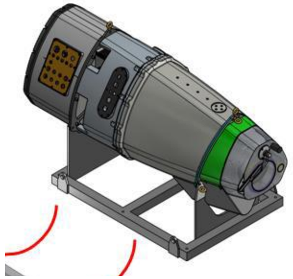


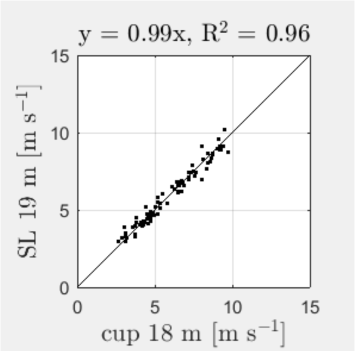
LiDAR installation & measurements

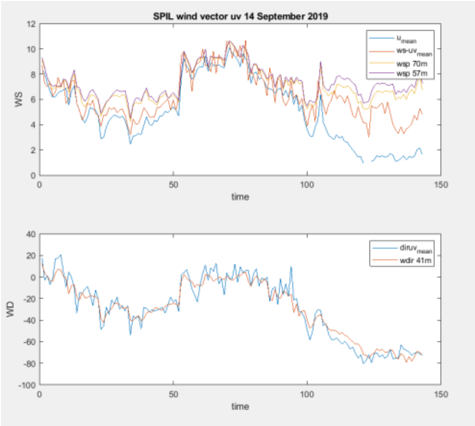


Deliverable D3.6 (DTU / OREC)

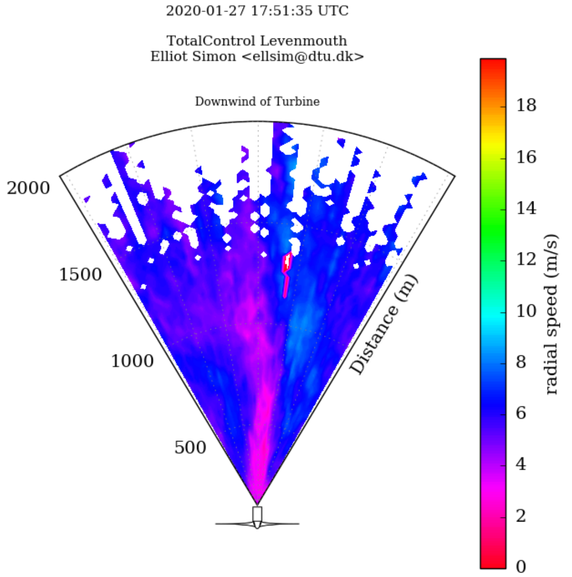
1. Forward facing ‘Spinner LiDAR’ to measure inflow







2. Rear-facing ‘WindScanner’ to measure the wake

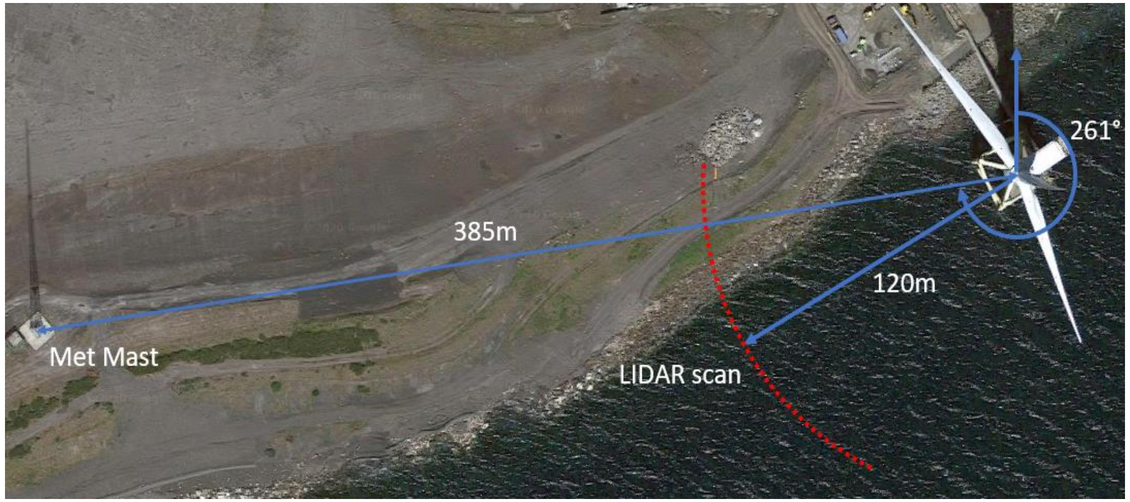


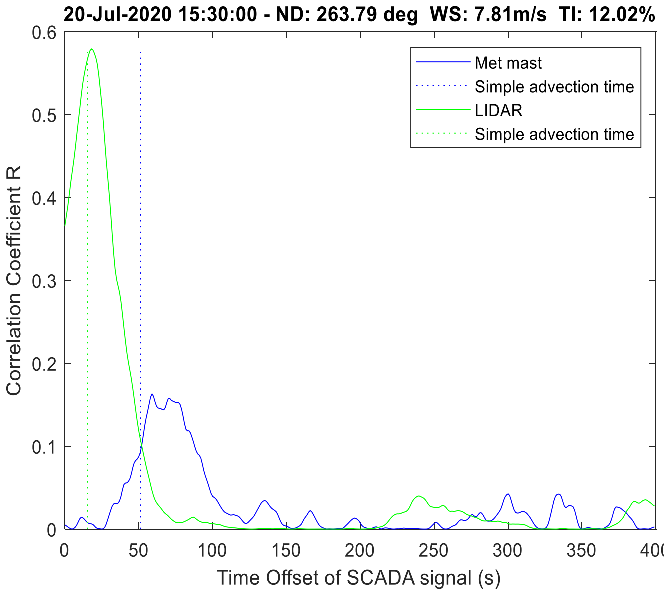
- Both installations completed in February 2020
- Calibrated vs met mast
- Spinner LiDAR: data provided for D3.9, and providing inflow measurements for D3.7
- WindScanner providing wake data for D3.7: yaw misalignment and power reduction tests

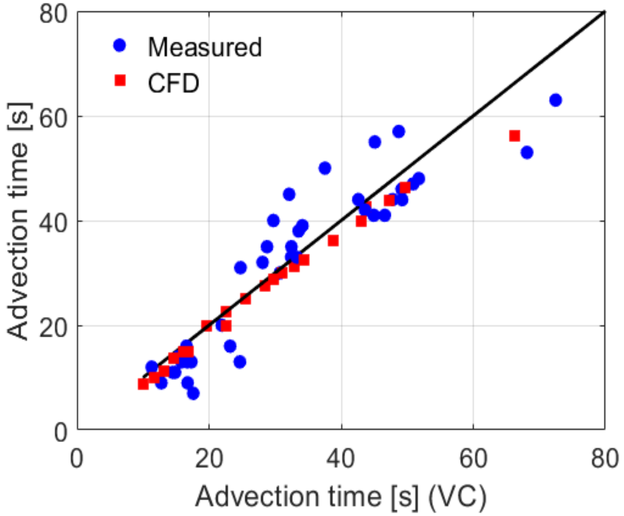
Wind field model for induction zone

Deliverable D3.6 (DTU / OREC)

- Improve understanding of turbine induction zone, and advection from LiDAR measurement to rotor plane
- Simultaneous data from mast, Spinner LiDAR and turbine (SCADA)
- Correlation analysis with time lags, to identify advection time
- Comparison with CFD flow modelling and advection time from vortex cylinder model
- Application to LiDAR-assisted control







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Controller field testing

Deliverable D3.7 (OREC, DNV GL, DTU)

- **Yaw misalignment tests** nearly complete (rear LiDAR to measure wake deflection)
- Controller upgraded to include the various new features to be tested
- **Down-regulation** (DTU algorithm as D3.2): ready pending final approval
- **Delta control** (DNV GL algorithm): ready and approved (simulations reported; not in Task3.1)
- **2P IPC** (as D3.5): ready and approved
- **Tower top IPC** (as D3.5)**:** ready and approved pending tower strain gauge → PLC connection
- **LiDAR-assisted control** (as D3.5) – ready pending final approval
- **Fast frequency response** (DNV GL algorithm)**:** in preparation; not in Task 3.1

Typical field test challenges! Delays due to LiDAR installation, safety approvals for tests, hardware faults (strain gauges, LiDARs, etc.), Covid-19 delays, weather windows, etc.

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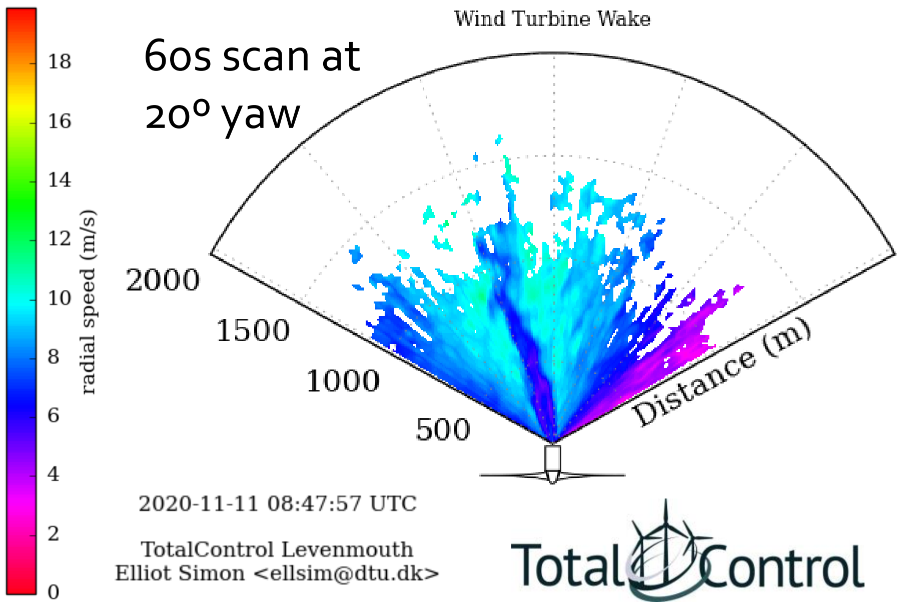
D3.7: yaw misalignment tests

- Running since late May
- Step-by-step: requirement to check loads before moving to higher wind speeds and yaw angles
- Good coverage of test matrix as of November
- $\pm 25^{o}$ yaw in progress

YAW	TI	WIND SPEED (m/s)										
		4	5	6	7	8	9	10	11	12	13	14
10	5%											
	10%		11	16	1	6	11	6	8	4	1	1
	15%	3	1	8	5	8	11	6	4	3		
-10	5%			1		1	1		4	1	3	1
	10%	4	2	9	11	5	6	9	13	3	2	2
	15%		1	2								
20	5%											
	10%											
	15%	2	2	3	6	2						
-20	5%											
	10%	2		1	1	4	1					
	15%		1	4	2							



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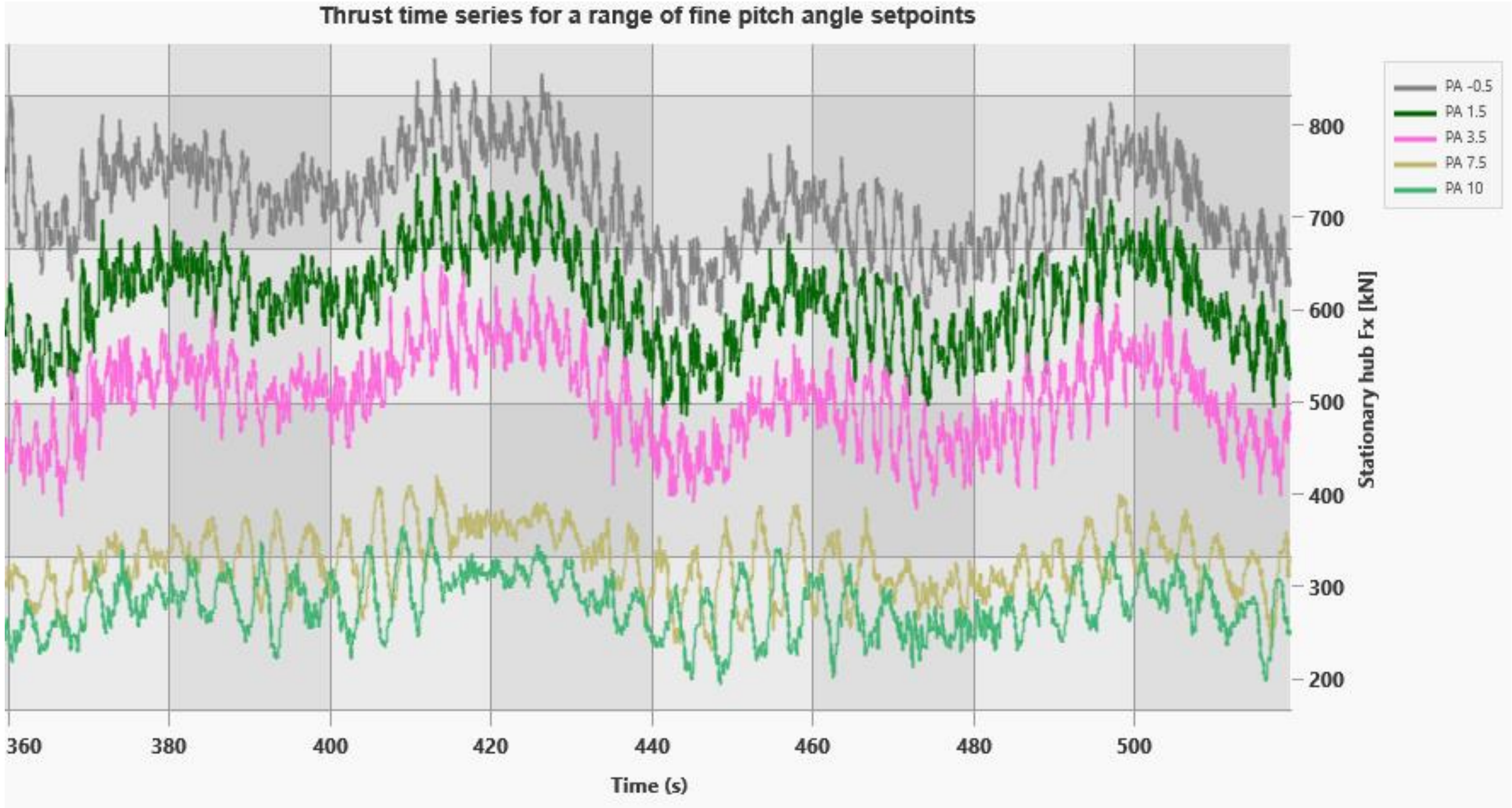
Delta control

Deliverable D3.7 (DNV GL)

- Thrust reduction (to decrease wake effects at downstream turbines)
- Maximise thrust reduction while minimising power reduction
- Change the fine pitch angle, torque-speed characteristic and maximum torque

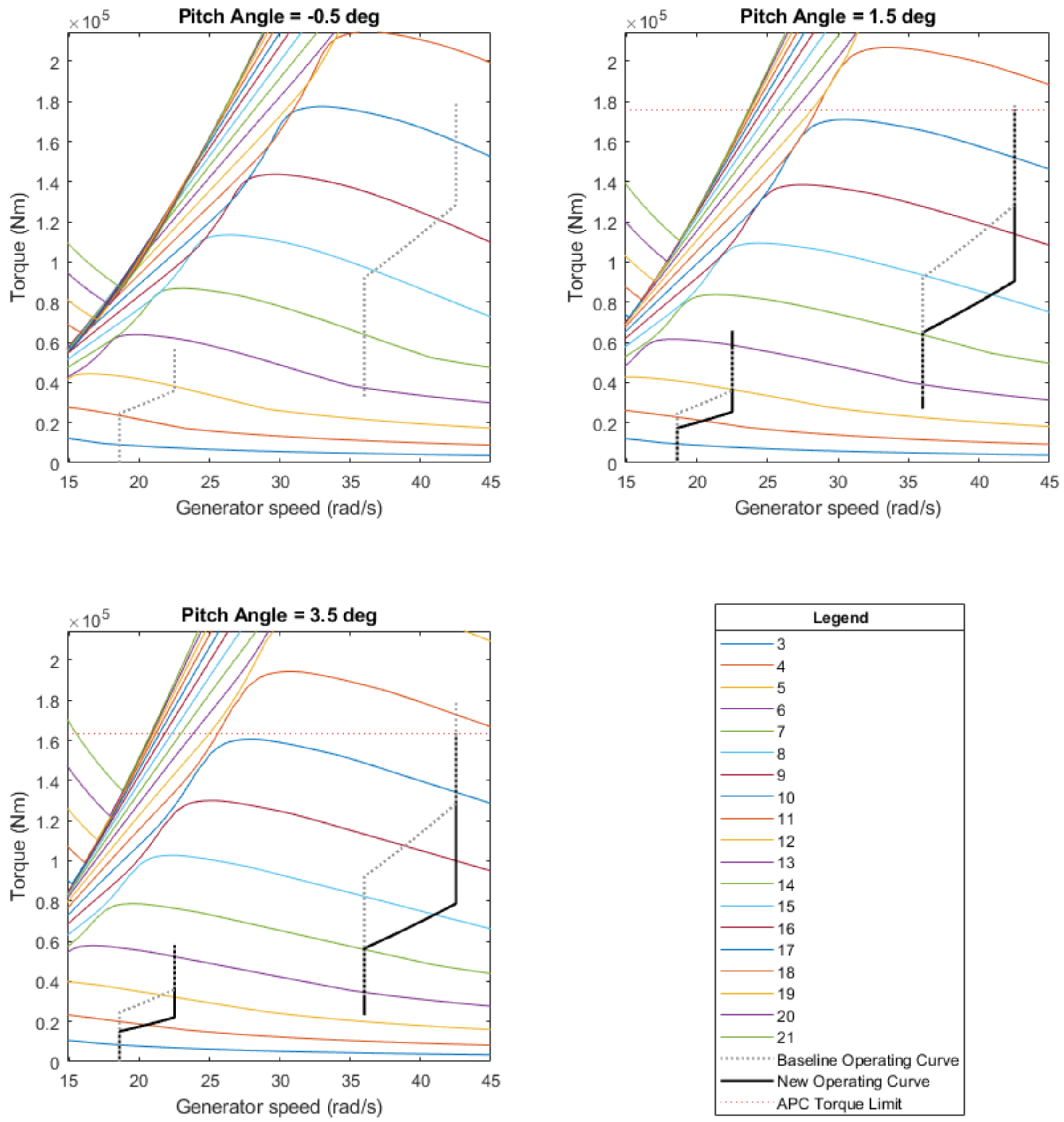
Simulation results:



Delta control

Deliverable D3.7 (DNV GL)

- Rotor speed will change
- Need to maintain stall margin
- Careful attention to interaction with the speed exclusion zone, to avoid any loading increases
- Report completed by DNV GL (no deliverable in Task 3.1)
- Testing approved by ORE



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Model predictive control implementation

Deliverable D3.8 (DNV GL)

- Aim was to create an MPC algorithm that could run on the 7MW turbine PLC
- Even harder than expected: no practical solution in sight
- New aim – to write a survey paper or report: drawing on solutions from the literature and the work reported in D3.4, and explaining all the real-world challenges for MPC on wind turbines
- Will fill the gap between academia and industry in the existing literature, which should catalyse a wider discussion with other experts around the world

WP3 schedule

- Finalise the D3.9 report on the induction zone model (January 2021)
- Complete Fast Frequency Response implementation (January 2021)
- Prepare the report on MPC (first half of 2021)
- Complete and report all the controller field tests over the coming year (need to dovetail tests as and when they are ready and approved and the wind conditions are appropriate)
- Project ends: December 2021