MAXFARM

MAXimizing wind Farm Aerodynamic Resource via advanced Modelling – an overview

Philip Hancock,
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SUPERGEN Wind Hub,
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Partners:
Imperial College London
Univ. of Loughborough
STFC-Rutherford Appleton
Univ. of Strathclyde
Univ. of Surrey

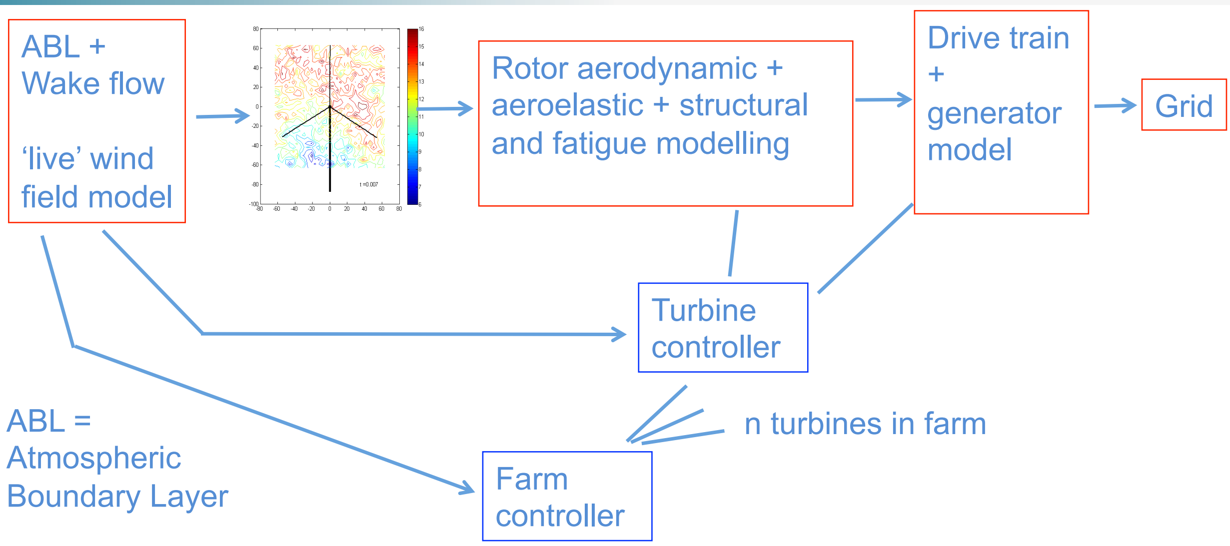
DNV GL – Energy
Catapult Offshore Renewable Energy
Catapult Satellite Applications
BMT Fluid Mechanics
Zephir LiDAR
Sgurr Energy
RES
Zenotech

Key Objectives

To improve:

- **modelling of offshore wind conditions**;
- **modelling of wake losses** within and downwind of offshore wind farms;
- **modelling of dynamic loading**, **fatigue** and **accumulated damage** for offshore wind turbines;
- **turbine life** and **overall wind farm efficiency**.

Interactions and Work Packages

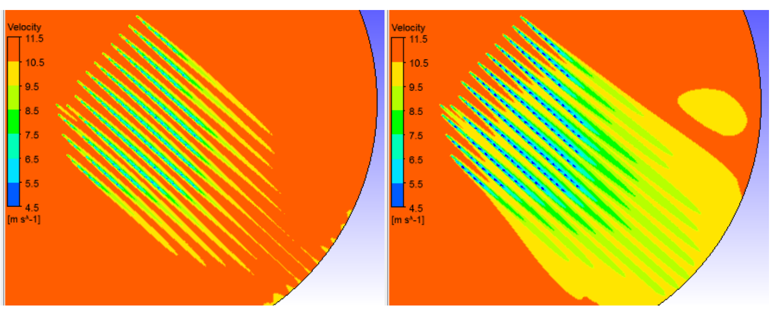


ABL = Atmospheric Boundary Layer

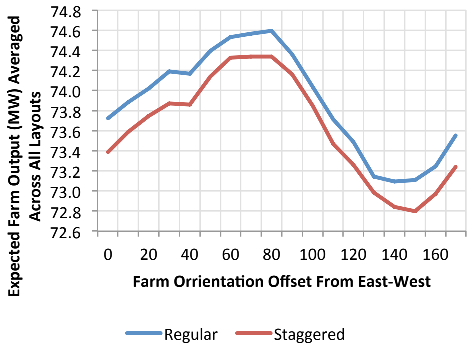
Wind Farm Analysis/Modelling (WP1, WP2)

- CFD + met data (e.g. ECMWF) & production data (e.g. Elexon)
  - wake effects in various farm layouts - existing and hypothetical
  - wake effects of farm orientation to wind rose
  - effects of atmospheric stability on farm productivity
    (effect of surface condition, weak inversion)

Very Unstable | Stable



small hypothetic wind farm – regular vs staggered



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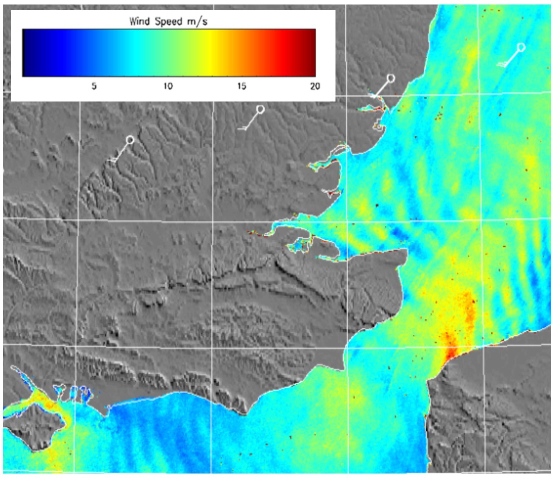
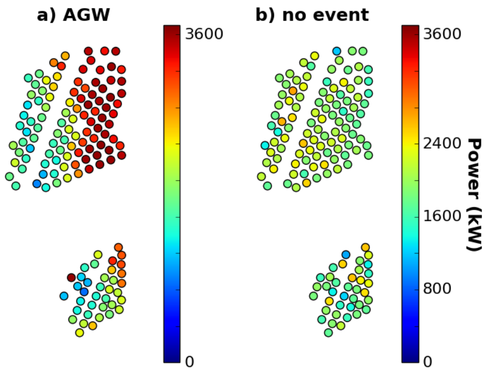
Wind Condition Analysis (WP1, WP2)

- Satellite mesoscale wind field data (provided by DTU)
- Events highlighted and compared to models
- WRF simulations to show effect on power timescales





Greater Gabbard

AGW = Atmospheric Gravity Wave

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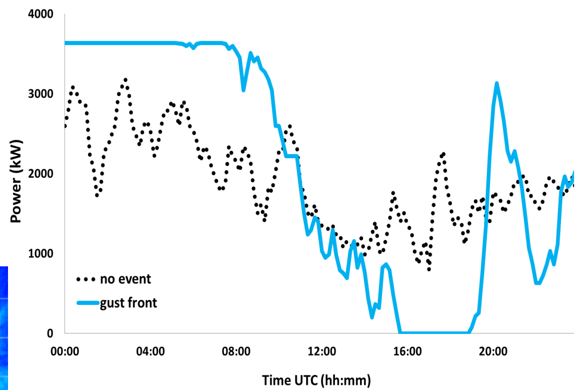
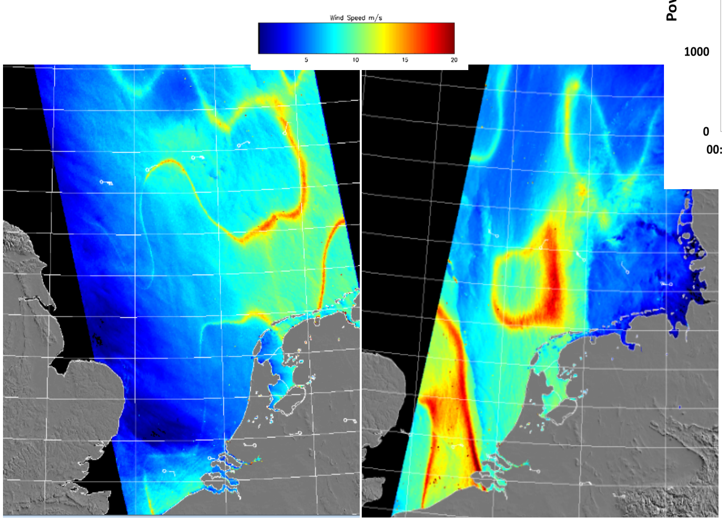
Wind Condition Analysis (WP1, WP2)

Estimated power output for a turbine at Greater Gabbard during gust front event vs. a non-event day at the same location.



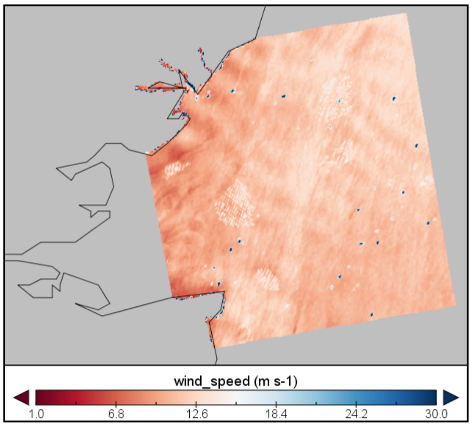
Siemens 3.6 MW turbine



Loughborough University

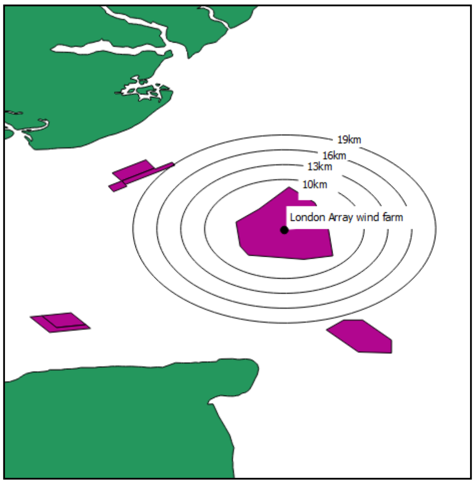
Wake losses from satellite measurement

(WP2)



Wind speed derived from satellite radar backscatter on the sea surface,

from Sentinel 1



Detecting wake effects from average wind speeds seen across many SAR scenes: Selecting on sample radii from a wind farm.

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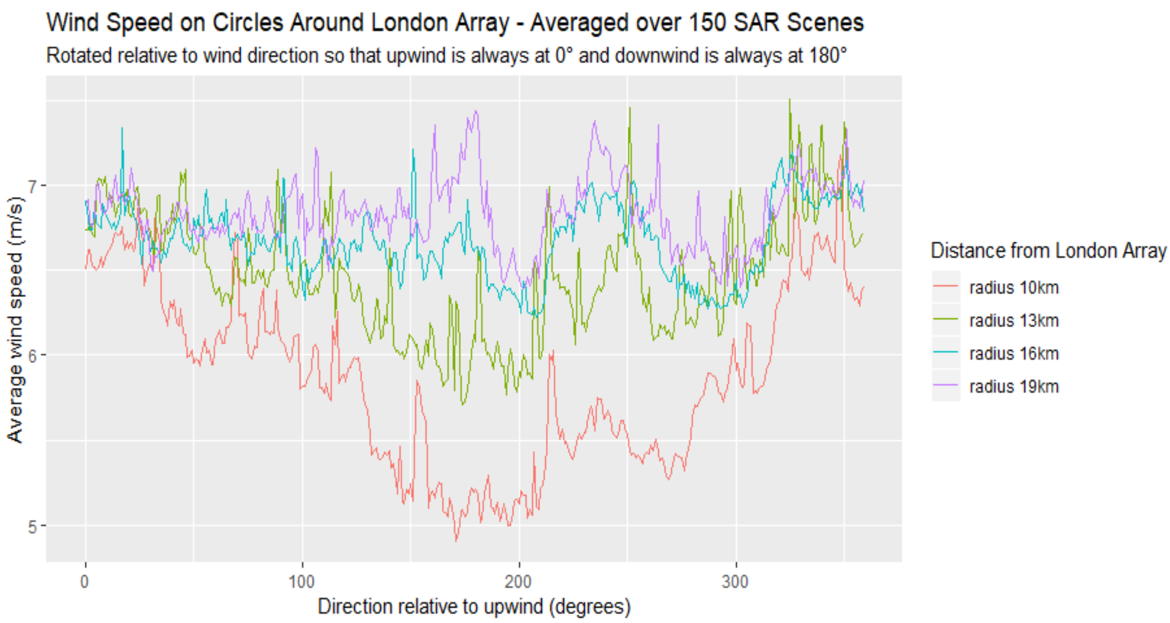
Rutherford Appleton Laboratory

Wake losses from satellite measurement

(WP2)



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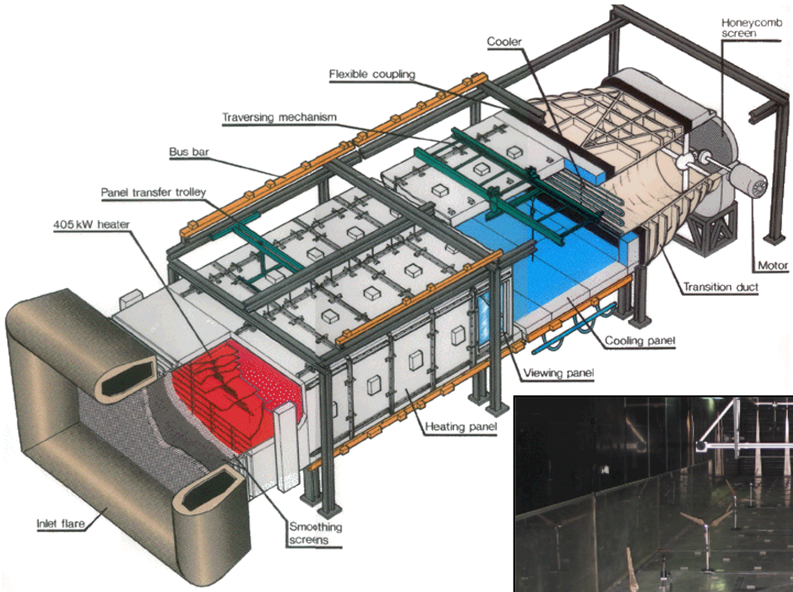
Effects of atmospheric stability (WP1, WP2)

EPSRC Pioneering research and skills



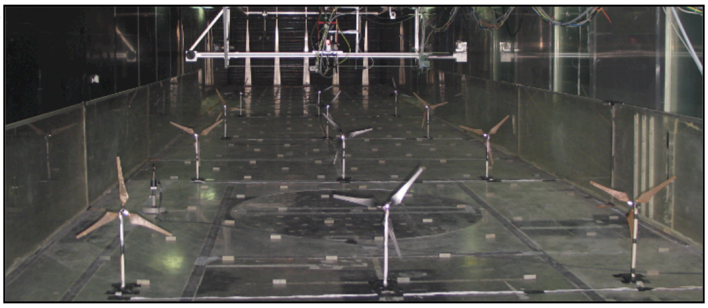
Cases:

Unstable

Stable - no inversion; with inversion

Neutral – datum cases

Working section:
20 m long; 3.5 m wide; 1.5 m high



Working section - Looking upstream

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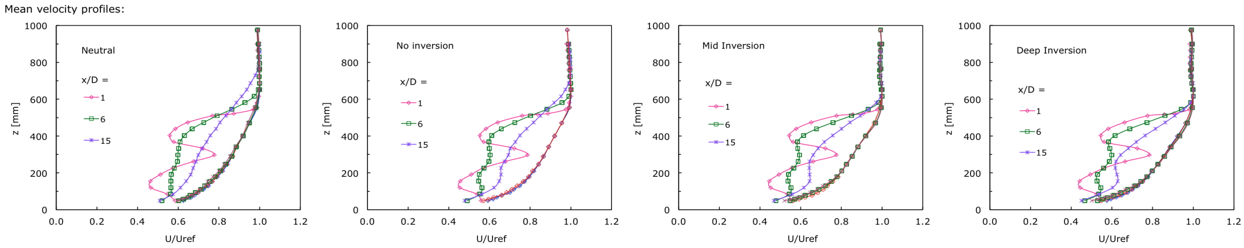
Effects of atmospheric stability (WP1, WP2)

EPSRC Pioneering research and skills

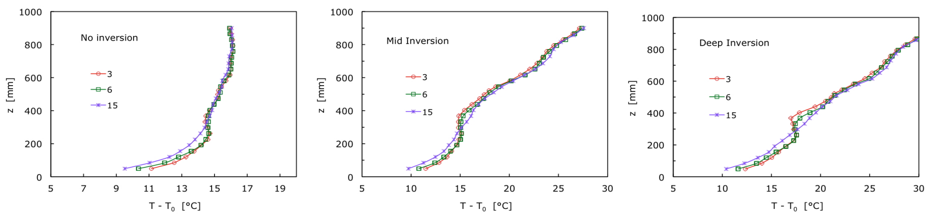
Neutral stability | Stable* + no inversion | Stable*+ 'mid' inversion | Stable*+'deep' inversion

Mean velocity profiles:

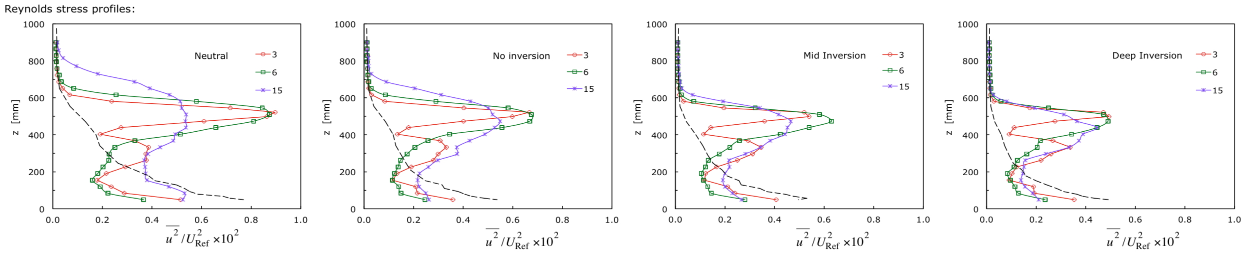


Mean temperature profiles:

* = moderate surface condition

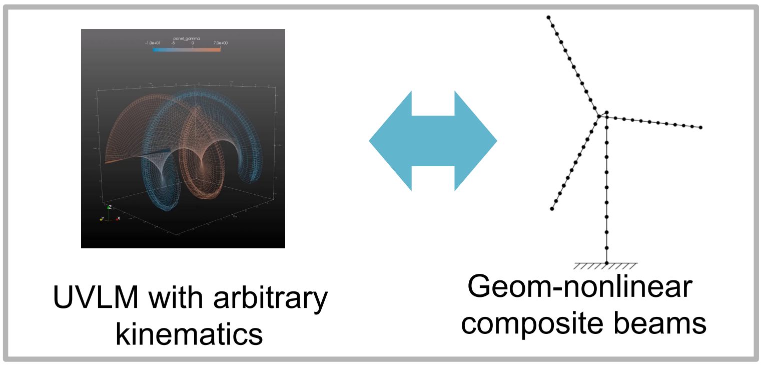


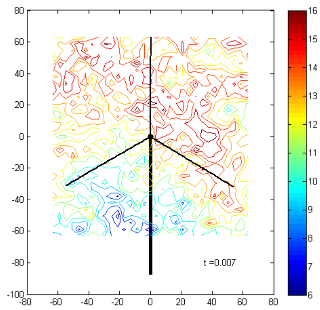
Reynolds stress profiles:



Aerodynamic-aeroelastic modelling (WP3)

- Baseline - In-house aeroelastic simulation framework (SHARPy)





- Time-domain, nonlinear solver
- Includes composites (aeroelastic tailoring), flaps, arbitrary inflow
- Numerically efficient (C++/Fortran), all wrapped in Python

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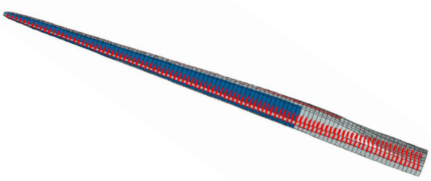
Interfacing with fatigue modelling (WP3)

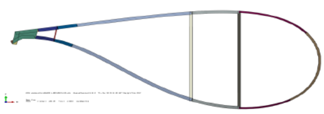
- Based on the DTU 10 MW Reference Turbine: 90m long blades.
- DTU - Abaqus shell model and cross section meshes/data
- STFC to apply loads from the IC aeroelastic model (aerodynamic, gyroscopic, …) to Abaqus shell model of a blade.

From 3D FEM to geometrically-exact beam model (GEBM)

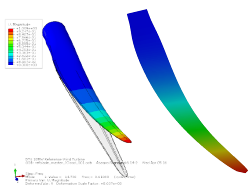
DTU 10 MW blade
High-fidelity FEM model



Cross-sectional reduction



3D FEM vs GEBM



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Aero-structure - model-order reduction (WP3)

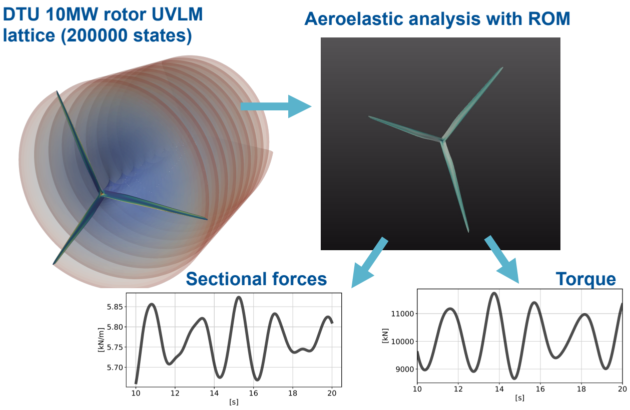
Efficient model order reduction of linearized aeroelastic system

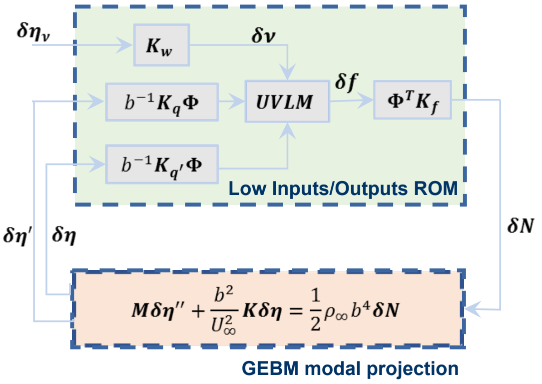
Projection over structural modes:

- ROM order comparable to No. inputs/outputs (**from 200,000 -> 40 states**)

Frequency-limited balanced truncation:

- ROMs at a fraction of the cost (**low-rank**)
- **Virtually no loss of accuracy**





Resulting ROM suitable for farm control integration & detailed fatigue analysis

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Wind farm control (WP4)

- Wind farm control objectives
  - maximise generated power
  - Provide ancillary services to grid
  - Minimise O&M costs

- Wind farm control design and analysis models are required.
  - Performance assessment is over full operating envelop.
  - Simulation should include the wind field & wakes, turbines (up to 100+) and wind farm controller.
  - Fast simulation execution times required.

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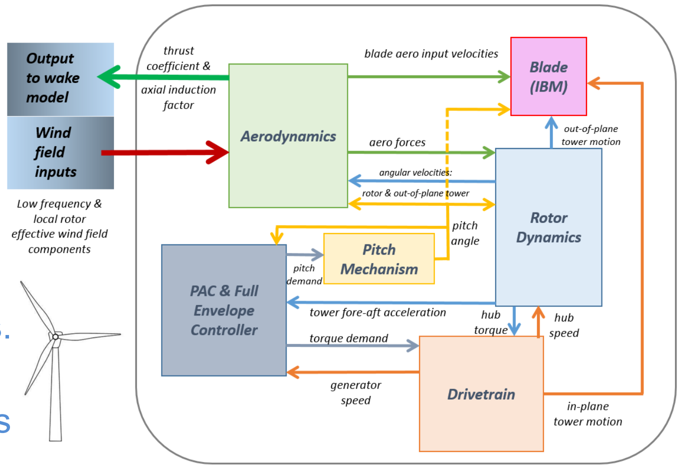
Wind farm control (WP4)

- SUPERGEN variable speed pitch regulated, 3-bladed, HAWT exemplar turbine.
- 5MW, other sizes to be added (10MW, …).
- Uses lumped parameter models for representing drive train, rotor and blade dynamics.
- Reformulated BEM based aerodynamic coefficient models to determine the thrust and torque at the rotor including dynamic induction lag.

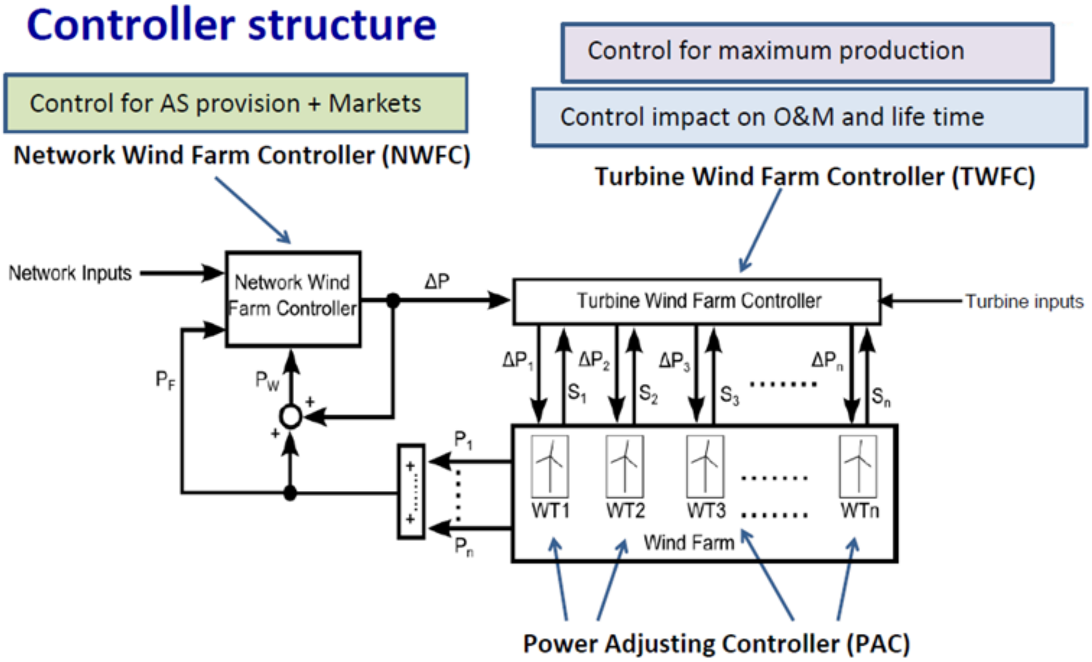


Simulation time, single WT for 600s:
Continuous = 18s
Discrete = 14s

- Continuous (Simulink) and Discrete (C/C++) forms available.

Wind farm control (WP4)

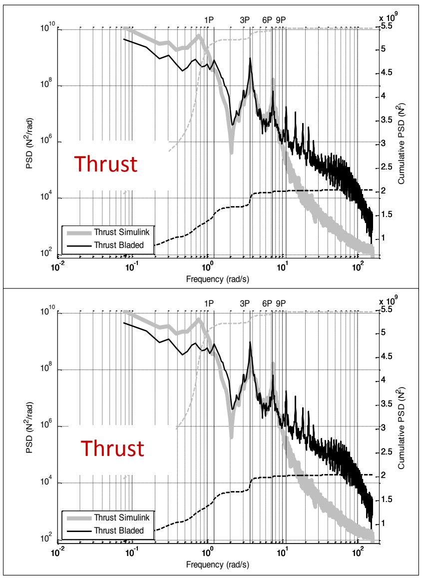
Controller structure



Wind Farm Controller Structure with Power Adjusting Control (PAC) Strategy

Wind farm control (WP4)

- Comparison of loads to Bladed

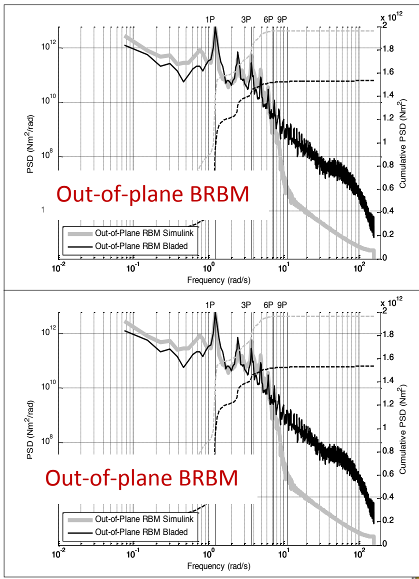


Loads with mean wind speed 8m/s

WF simulation

BLADED

Loads with mean wind speed 14m/s



Mean wind speed ~ 14m/s Turbulence intensity ~ 10%

MAXFARM –

We have made good progress in bringing together key elements of
- wind resource
- wakes and inflow
- fluctuating loads and fatigue prediction
- and an encompassing control environment.

There is much more to do.

Thank you