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Effect of Tracking Grid Power Command on Drivetrain Degradation

A Multiscale Farm Control Problem

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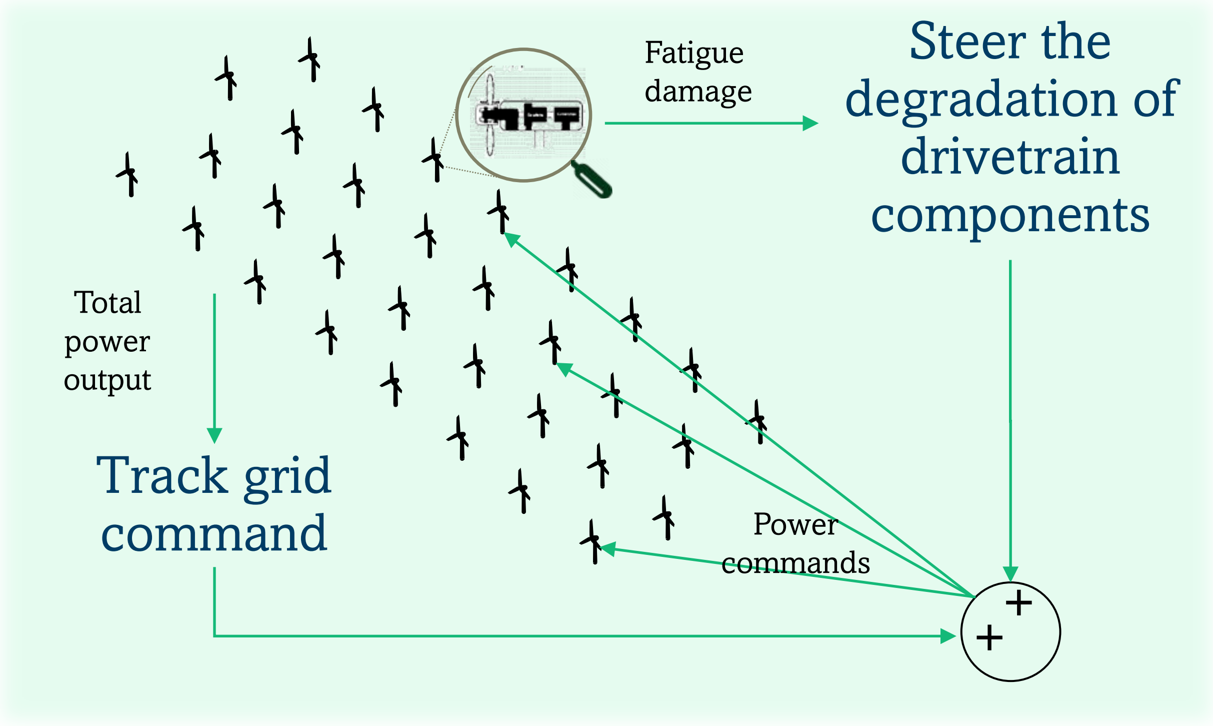
Motivation

Holistic and future-proof operation of wind farms

- Larger penetration of renewables – need for grid support
  - Tracking of power command from grid – production below maximum
- Further from shore – increased maintenance costs
  - Repair of drivetrain components – frequent and fastidious
- Need for a simulation tool that can:
  - Capture farm-wide processes: wind speed variations, farm control *minutes to hours timescale*
  - Capture local degradation processes: detailed aero-hydro-servo elastic response, *subsecond to seconds timescale*
  - Be used for control & structural design: computationally efficient

Curtailed operation/overplanting

Added degree of freedom for farm control



Efficient multiscale wind farm simulations

Enhancing NREL's FAST.Farm ecosystem

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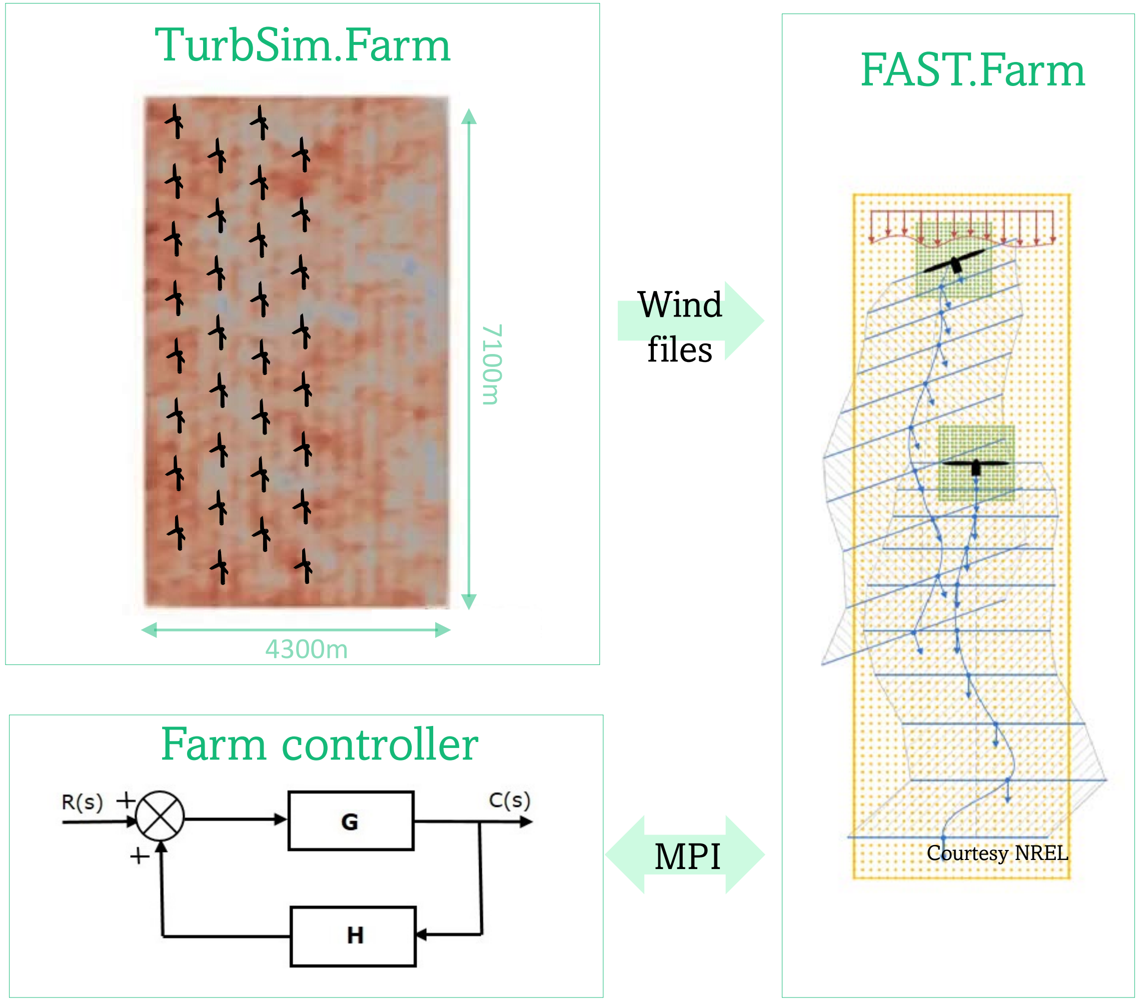
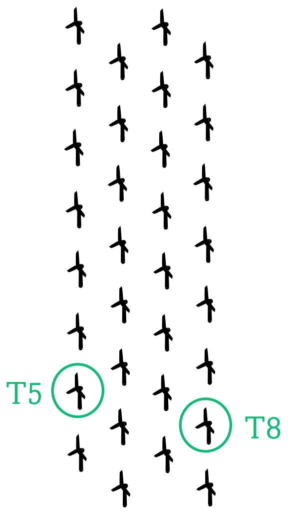
- TurbSim.Farm
  - Mesoscale (farm-wide) spectra and coherence models
  - Space-averaged coherence to reduce number of DOFs for farm-wide wind field
  - No frozen turbulence assumption
  - Possibility for refining to high-resolution turbulence box from aggregated wind speed
- External farm controller
  - Farm controller = MPI server in own modelling environment
  - Turbine controllers = MPI clients

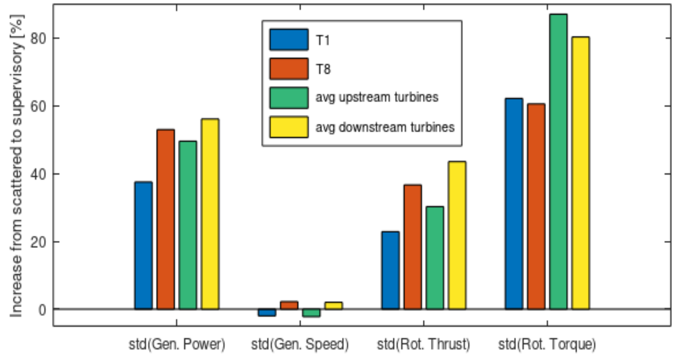


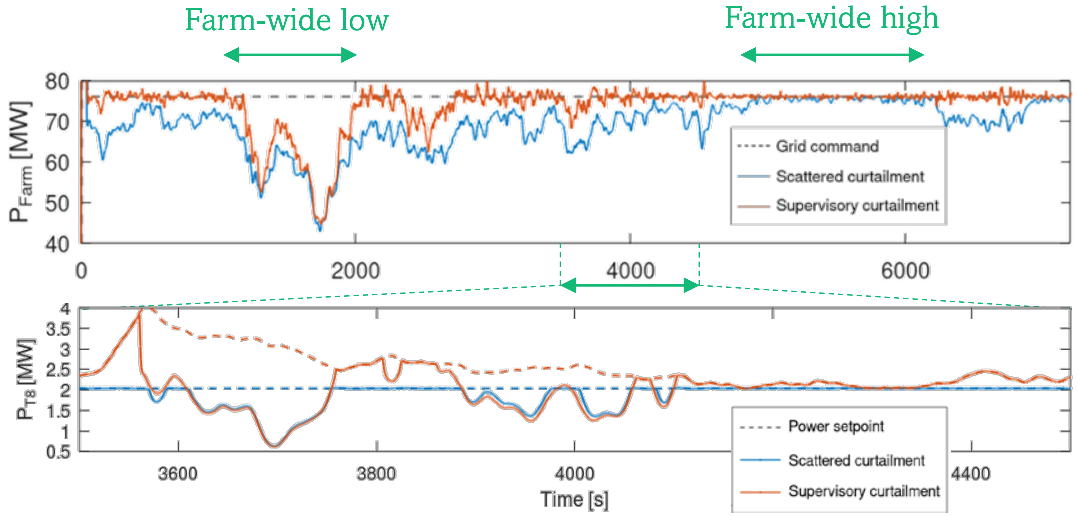
Curtailed operation

Control algorithm & case study

- Power tracking
  - Turbine controller: below-rated PI pitch control, tracks a power setpoint up to available power
  - Scattered curtailment: each turbine tracks indepedently a constant de-rating power command
  - Supervisory curtailment: the PI farm controller dispatches power commands to compensate for wind speed variations between turbines
- Downscaled TotalControl reference wind farm
  - 32 x NREL 5MW turbines, staggered 5D spacing
- 10 m/s, 0 deg, 80% curtailment, 2h simulation
- Results:
  - Supervisory controller ineffective in periods with farm-wide lows and highs in wind speed
  - Else effectively tracking grid command to the cost of increased power, torque and thrust fluctuations at the turbine level





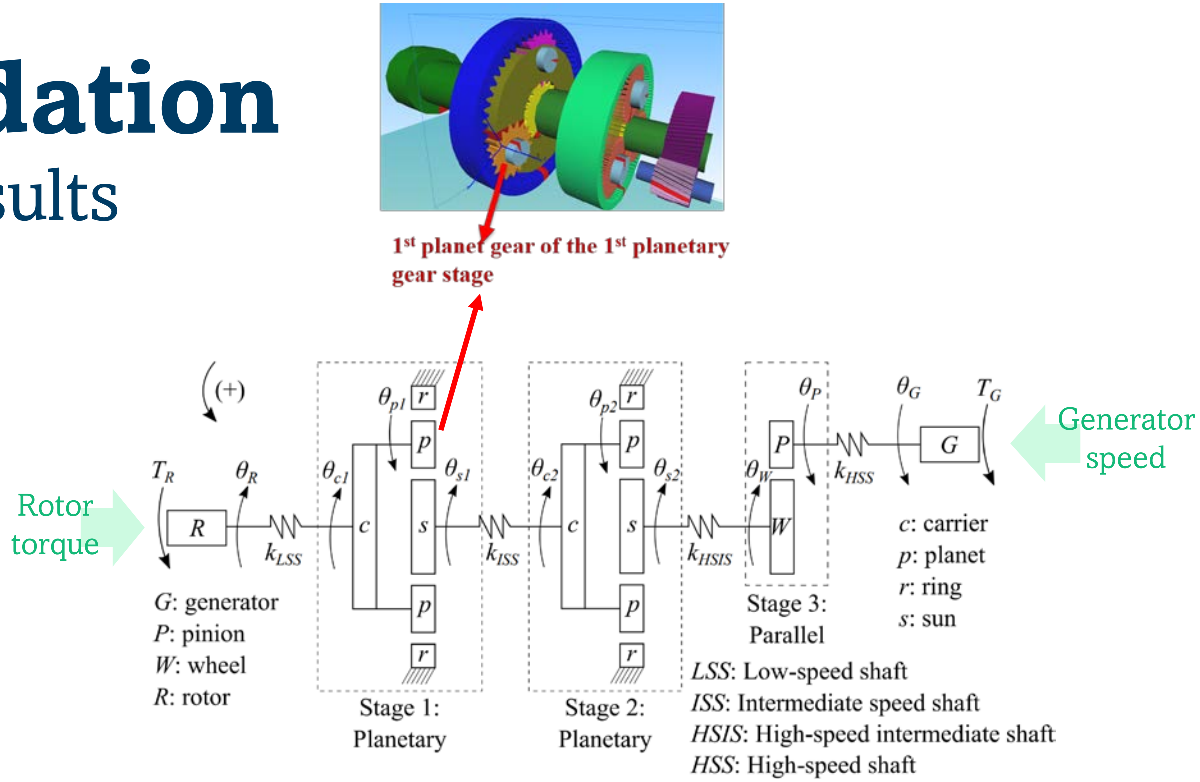


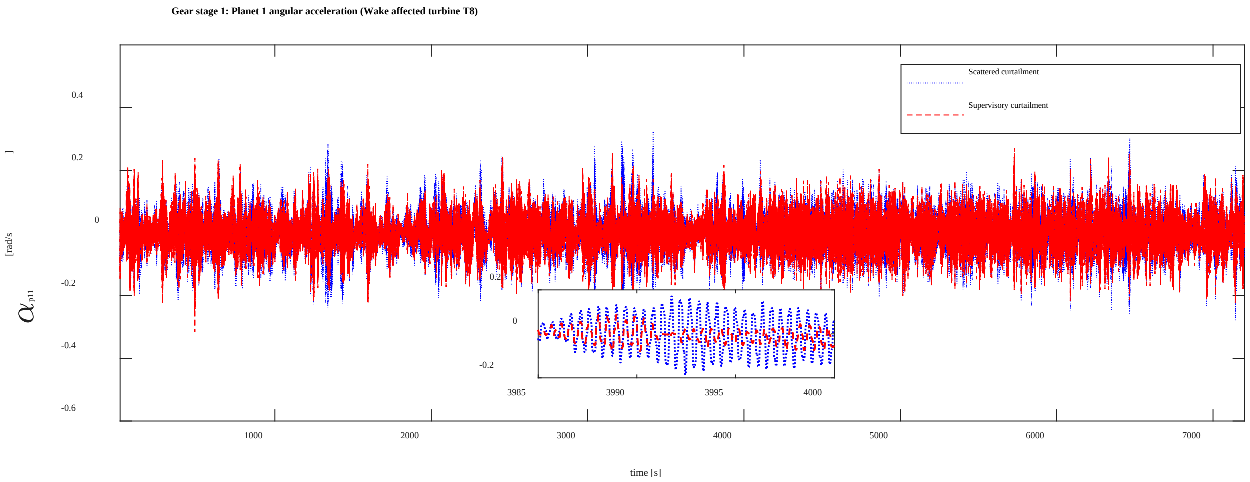
Drivetrain degradation

Model and preliminary results

- Linear state-space drivetrain model calibrated from high-fidelity simulation data
  - Torsional model $\mathbf{J}\ddot{\boldsymbol{\theta}} + \mathbf{D}\dot{\boldsymbol{\theta}} + \mathbf{K}\boldsymbol{\theta} = \mathbf{T}$
  - Looking at angular accelerations as temporary proxy for degradation
- Refined wind speed, fully elastic OpenFAST model for Turbines nr 5 and 8 as input
- Results: the turbine controller is critical
  - Closed-loop resonant oscillations dominate the drivetrain response, independently on farm control strategy
  - More frequent mode switching between curtailed and maximum power control modes dampens this effect locally

→ A more realistic power tracking turbine controller is necessary

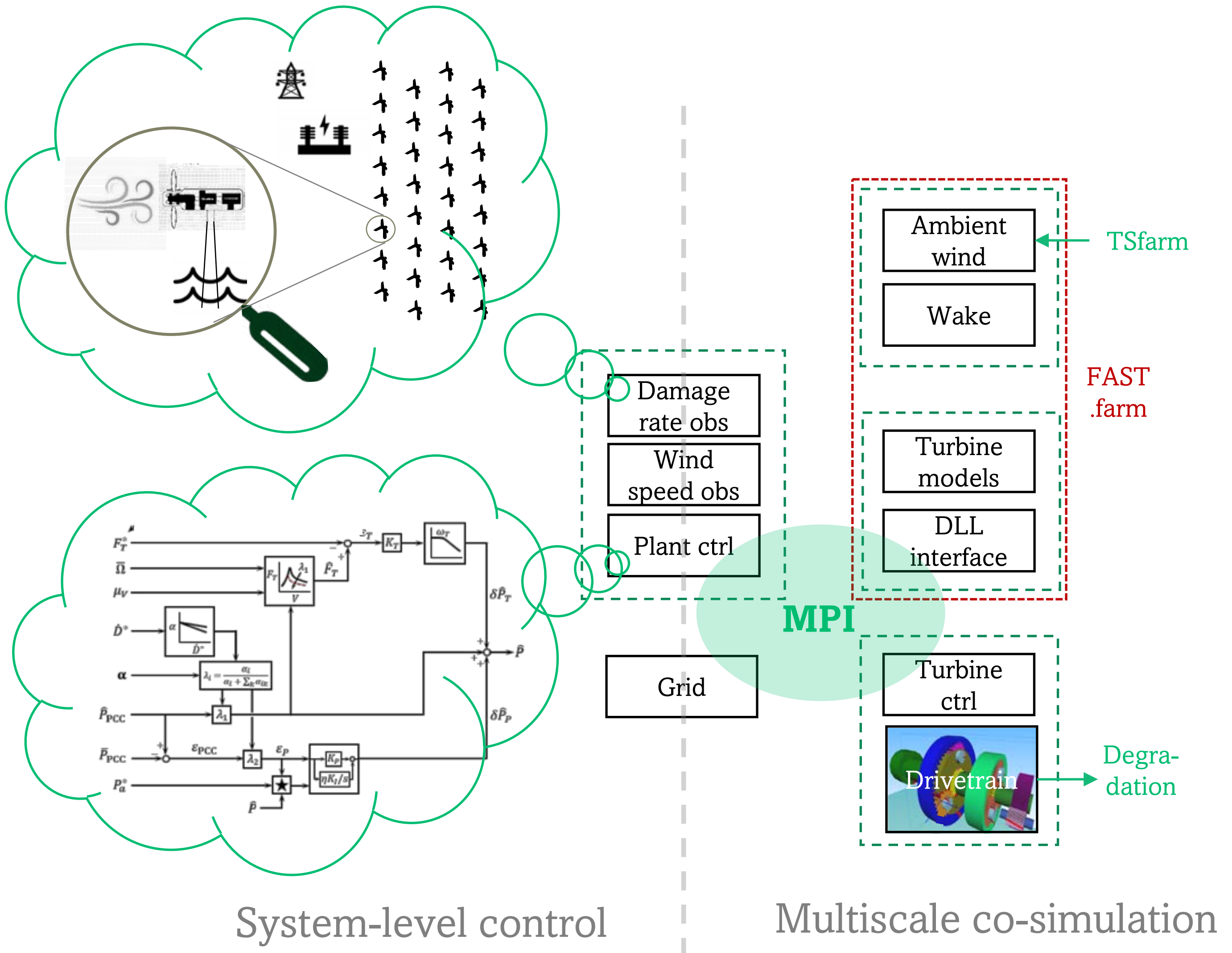




Outlook

From decoupled analysis to co-simulation, from power tracking to holistic control

- Fully coupled co-simulation with drivetrain model
  - Using time-domain drivetrain response to get stress/loads and degradation to inform control algorithm
  - Coupling with generator and grid to study electro-mechanical interactions
- Toward holistic control
  - Combining grid support with mitigation of asset degradation
  - Coupling with frequency-domain wind farm model for damage estimation



Thank you!

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