Studying wind farm frequency regulation using high fidelity wind farm simulations

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Outline

Introduction

Why is this an interesting topic?

- Increasing wind generation has profound implications for grid operations

Current practice:

- Ancillary services are used to maintain grid stability
- Traditional generators have most responsibility to take part in ancillary services
- Wind power has not been part of these vital grid services, except for active curtailment

Where we're headed:

- As wind power production increases, grid operators are considering requiring wind farms to be capable of providing many of these services

Research goals:

- Leverage large eddy simulations of wind farms to allow wind farms to provide secondary frequency regulation (one type of ancillary service)

Frequency regulation

- Power grid frequency is maintained by matching active (real) power generation and load
- Particularly important after a major grid disturbance (e.g. generator of transmission line failure)
- Frequency regulation occurs over many timescales

	Primary	Secondary	Tertiary
Purpose	Limit rate and magnitude of frequency excursion	Restore system to nominal frequency	Manual balancing of system after failure
Start time	seconds	seconds – minutes	minutes
Duration	$\sim$ 15 min	minutes – hour	hours
Control	Generator	Grid operator	Grid operator

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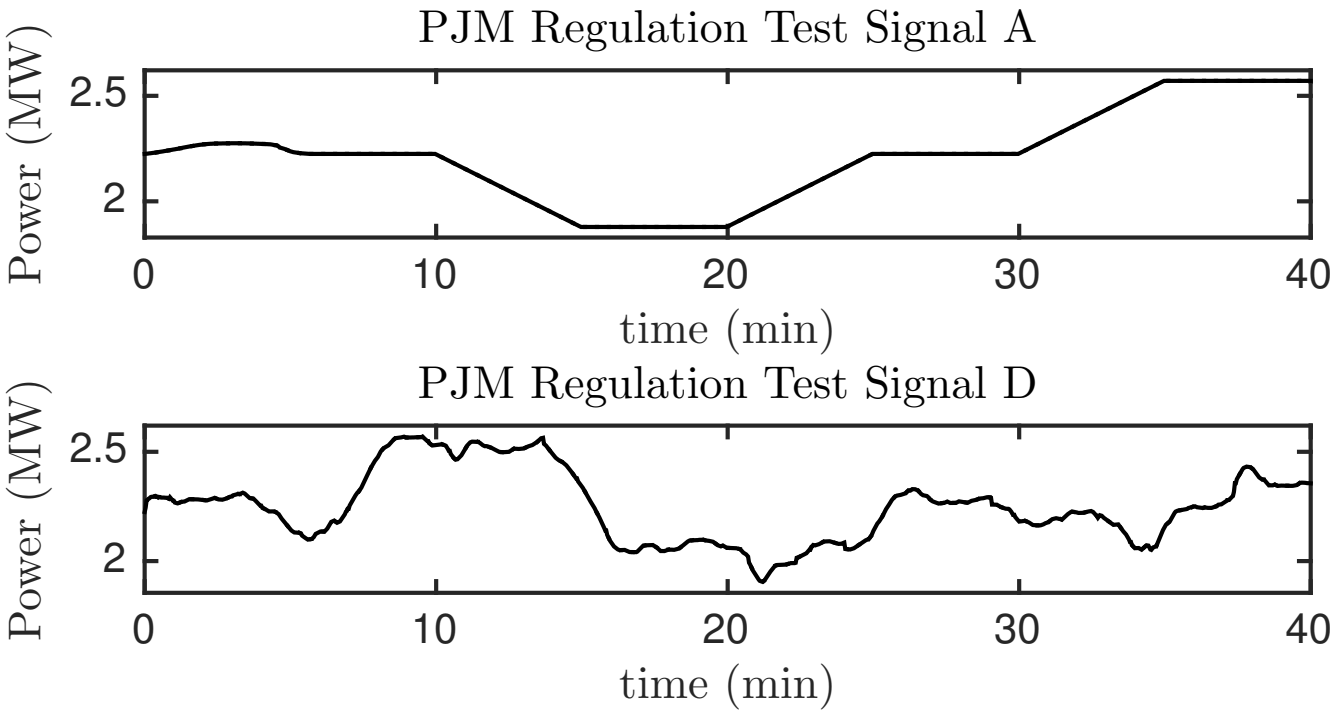
Secondary frequency regulation

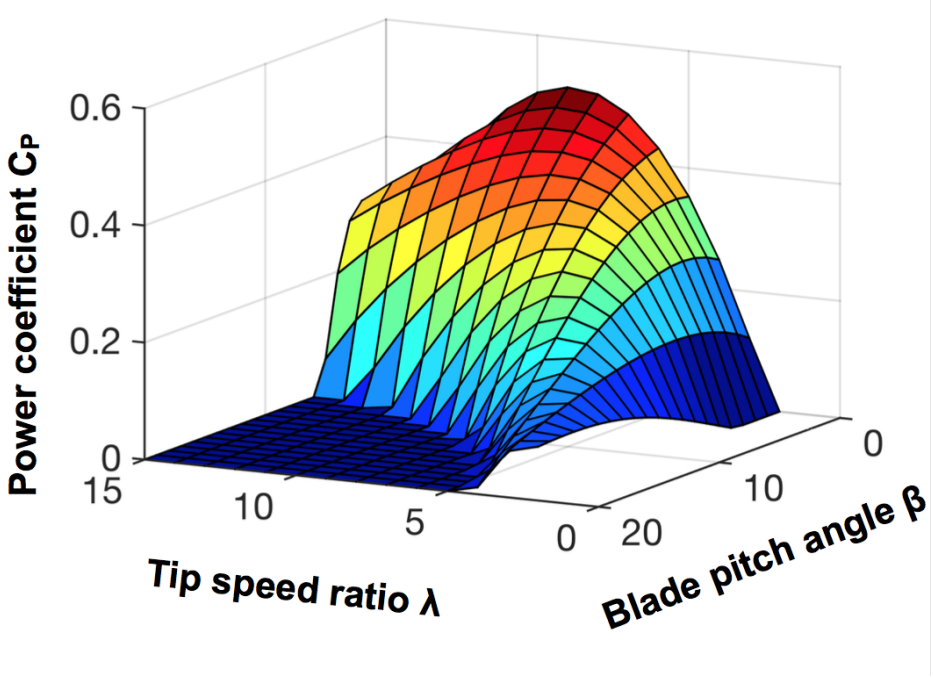
- Participating generators are required to track a regulation signal
- Reference signal may be:
  - Balance control (Absolute power reference signal)
  - Delta control (Percentage of available wind power)



Prior work (traditional control)

Many studies have looked at using wind turbines for secondary frequency regulation.

- Power is controlled by using the power coefficient curve
- The operating power production is derated from the maximum value.
- Tip speed ratio and blade pitch are controlled to regulate power production



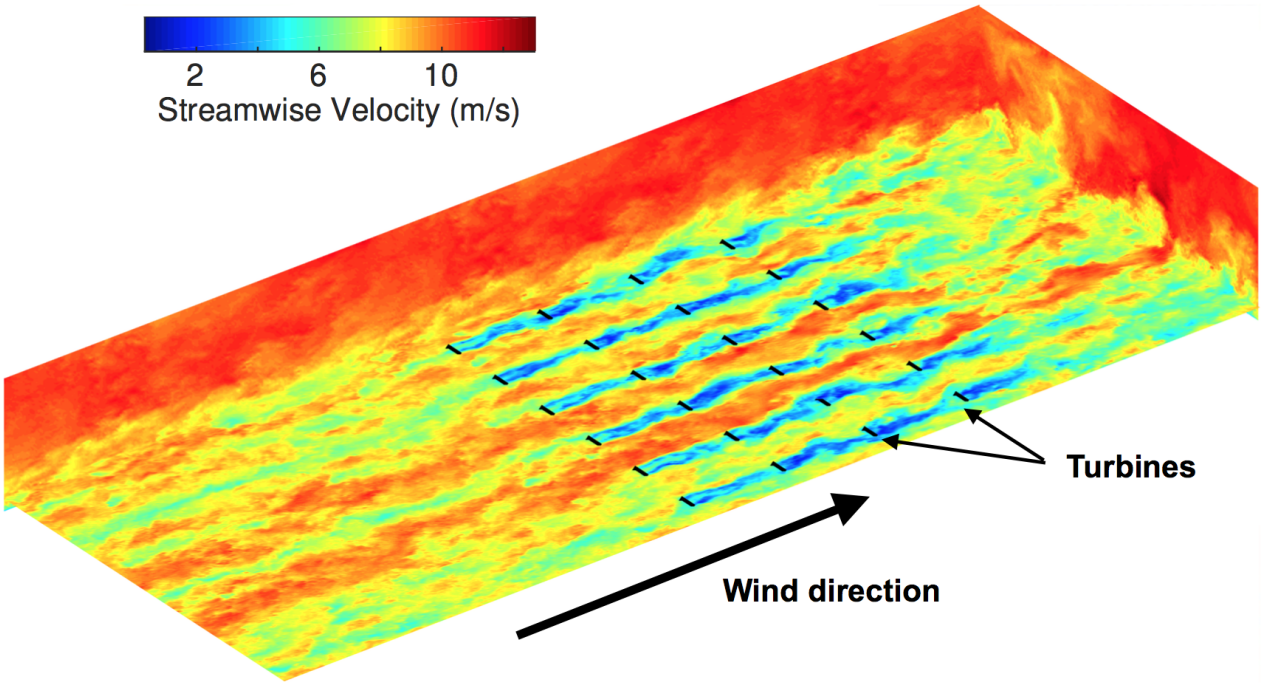
Shortcomings:

- Does not consider unsteady aerodynamic effects
- Cannot be easily applied to an entire wind farm because of wake interactions

Large eddy simulations

Incompressible filtered Navier Stokes equations:

$$\partial_t \tilde{u}_i + \partial_j \left(\tilde{u}_i \tilde{u}_j \right) = - \partial_i \tilde{p}^* - \partial_j \tau_{ij} + f_i$$
$$\partial_i \tilde{u}_i = 0$$



24 Turbines:

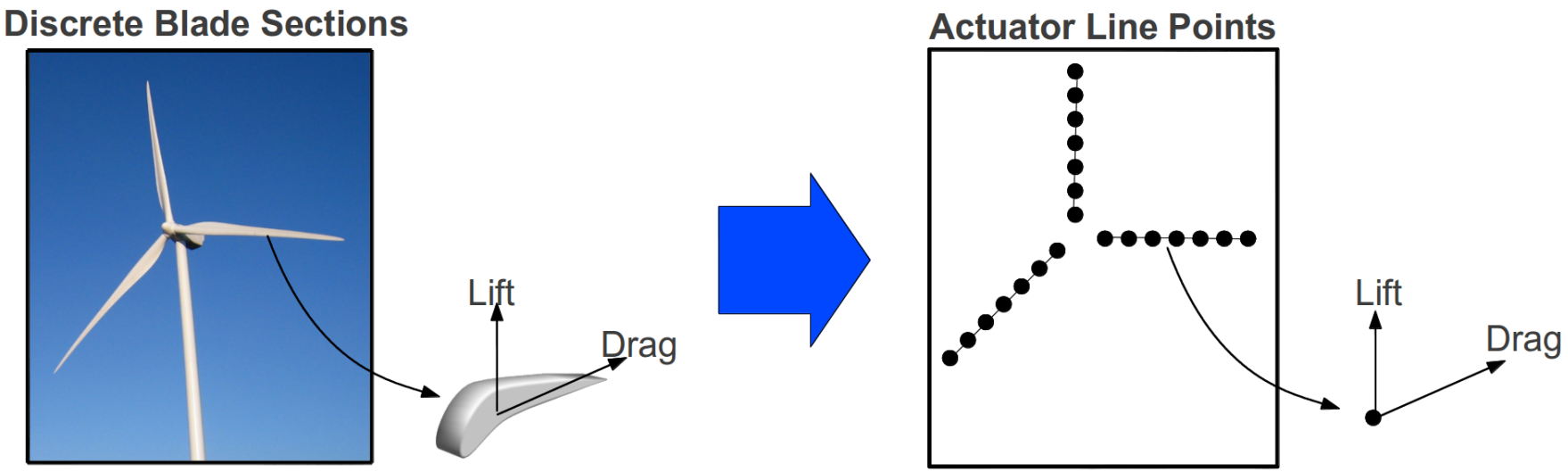
Domain Size:
$9 \times 3 \times 1$ km

Grid Size:
$576 \times 192 \times 64$

Pseudo-spectral concurrent precursor simulation

Turbines added as forcing term

Actuator line model



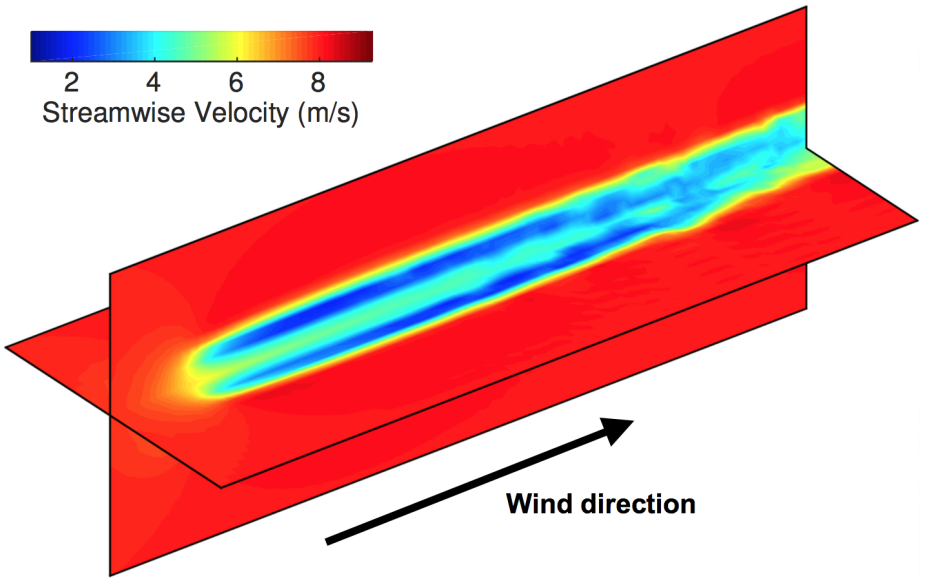
- Blade sections represented by point forces in computational domain
- Lift and drag found by sampling local velocity
- Calculated forces applied on LES domain through gaussian filter

Power and thrust coefficients

- Accurate power and thrust coefficient curves are need to implement frequency regulation controller
- Curves usually found using blade element momentum (BEM) theory
- Simplicity of BEM and coarse resolution of simulations means curves will not match

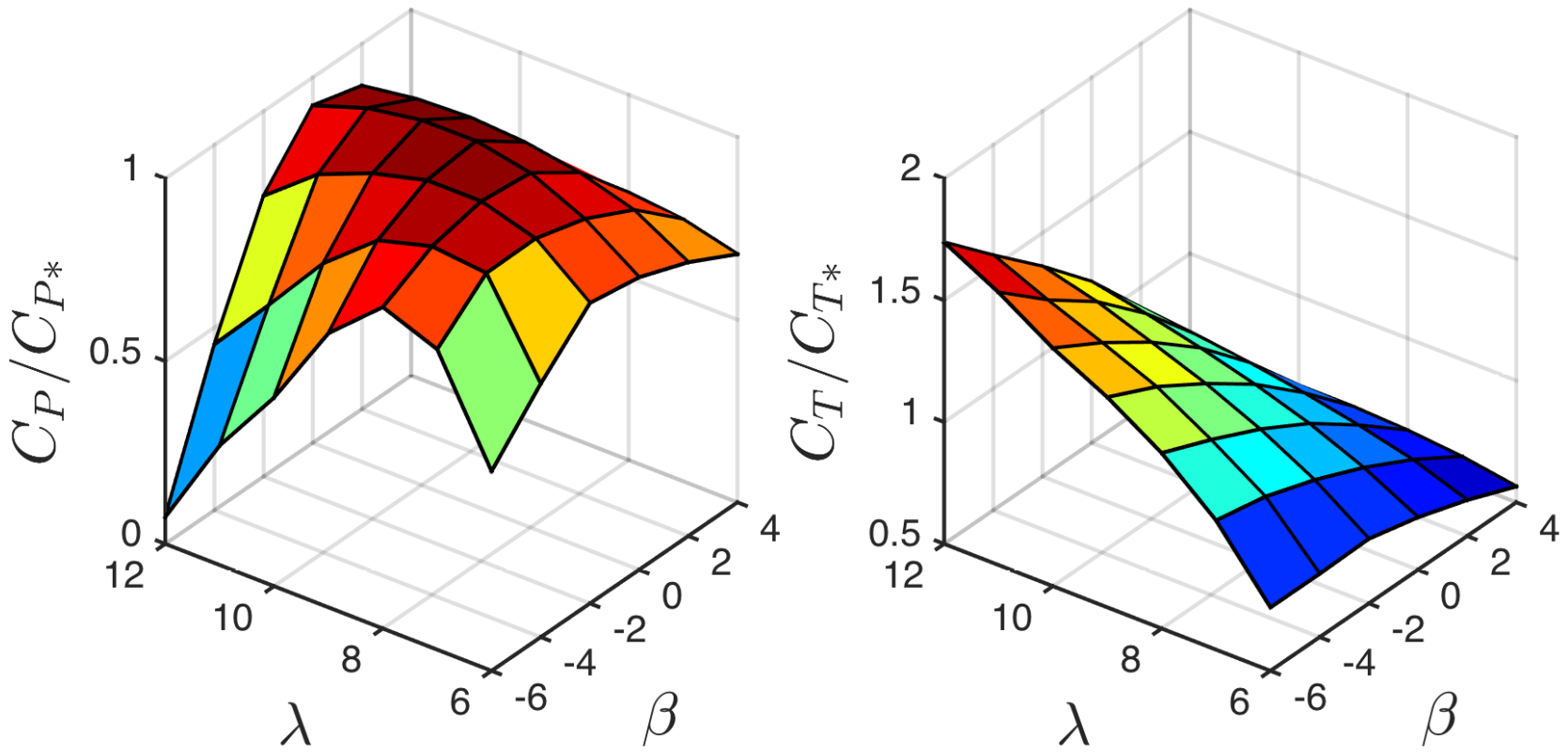
Simulation curves generated:

- Uniform inflow at 8 m/s
- Grid resolution of $\Delta x = \Delta y = \Delta z = 16$ m
- On $2.048 \times 1.024 \times 1.024$ km domain



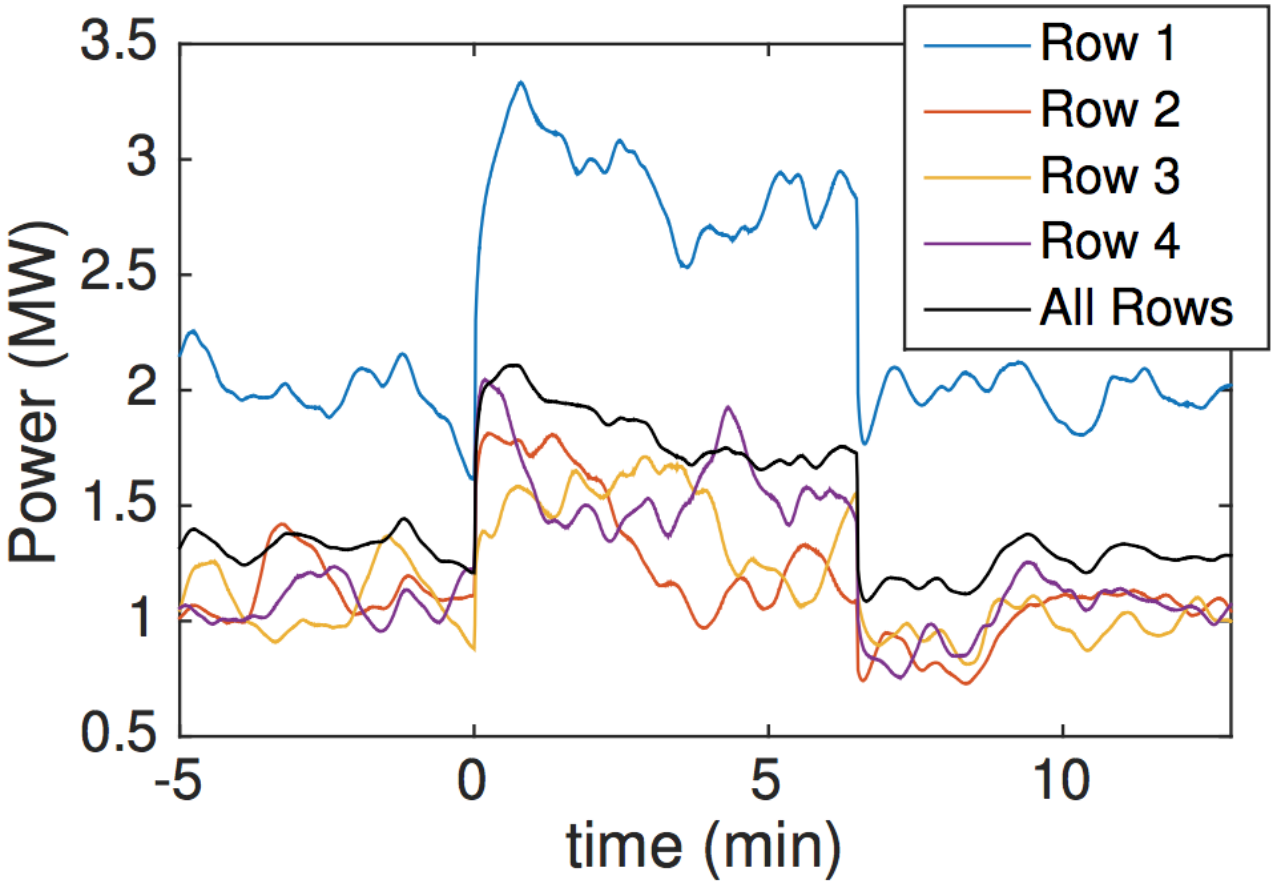
Power and thrust coefficients

- Normalized by optimal power coefficient
- Gives correct trends



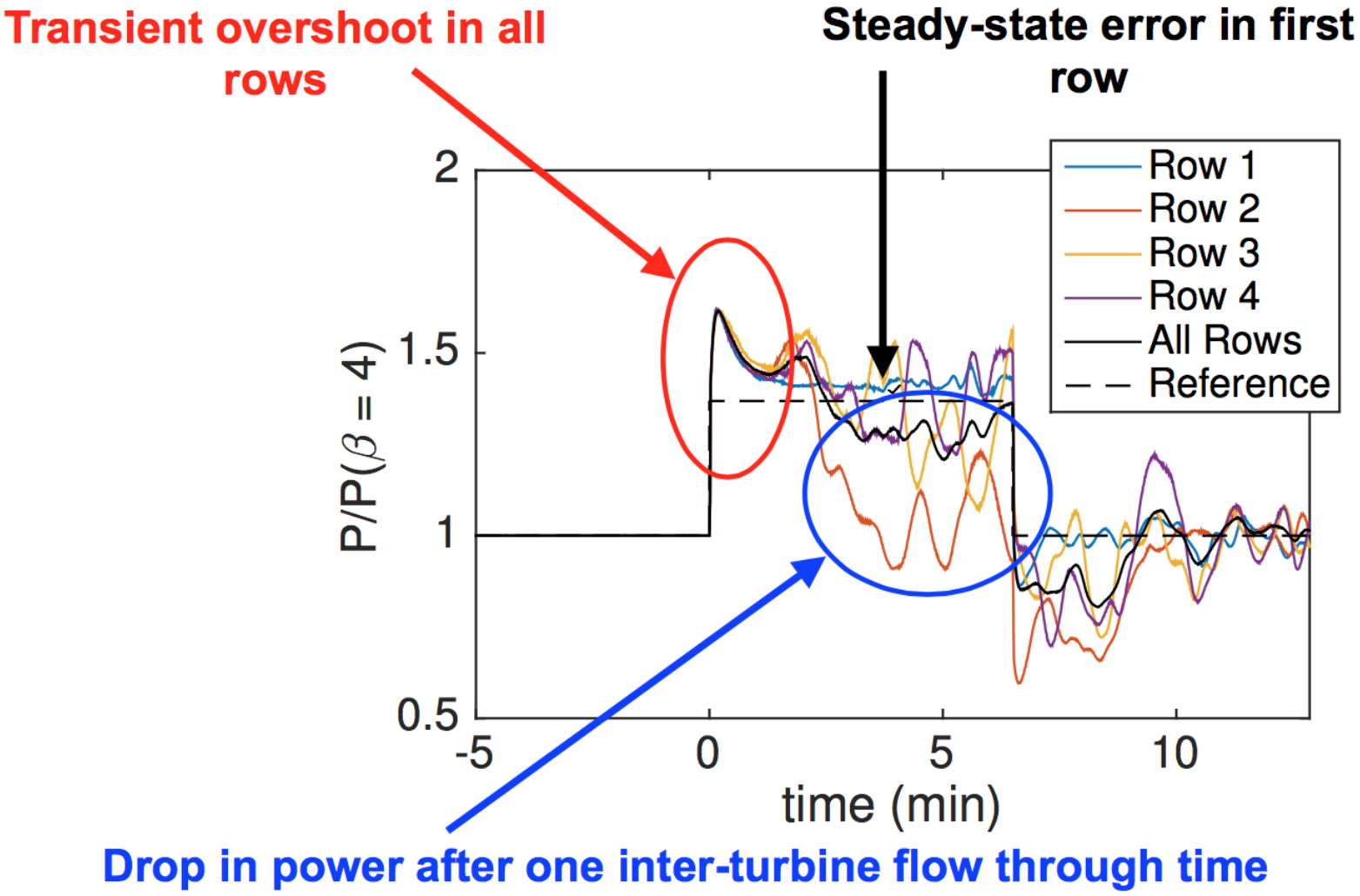
Testing traditional control

- Traditional control tested on a 24-turbine wind (4 rows of 6 turbines)
- Blade pitch angle changed from $\beta = 4^\circ$ to $\beta = 0^\circ$



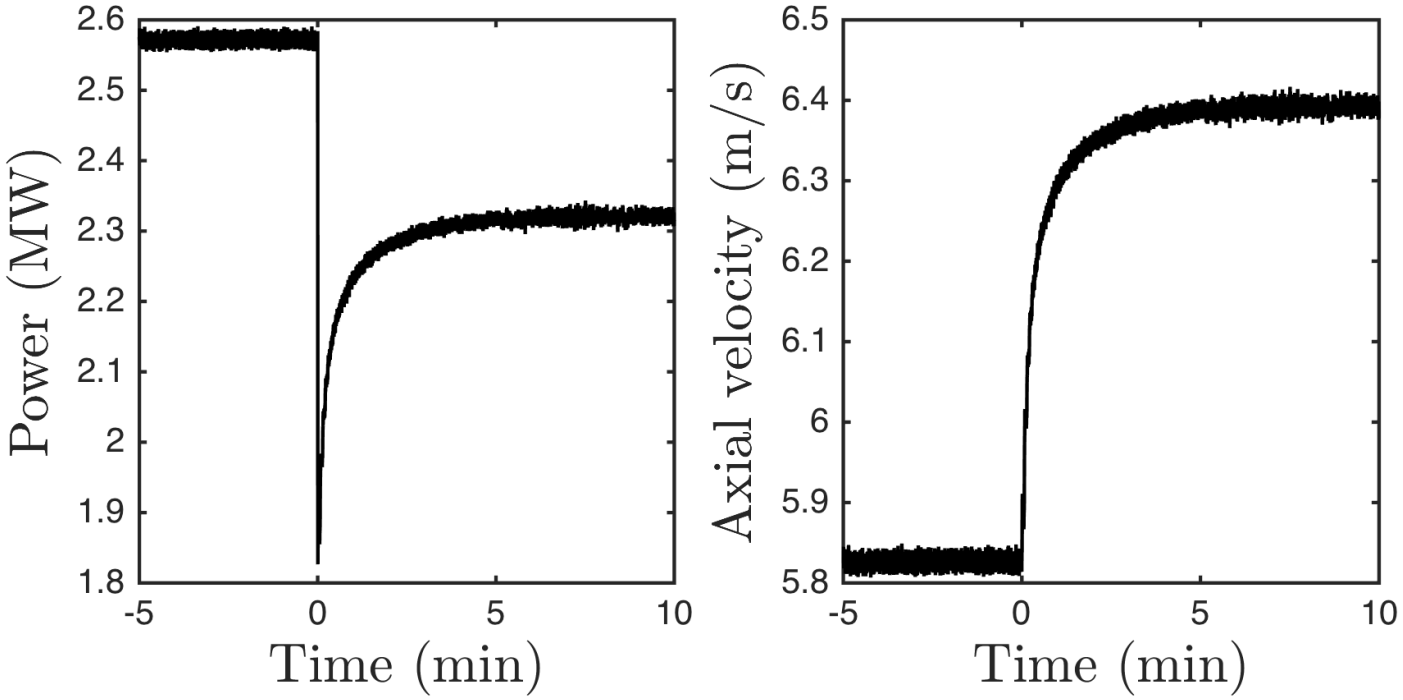
Testing traditional control

Comparing to power output with no change in pitch angle:



Addressing the transient overshoot

Response of pitch change in uniform inflow:

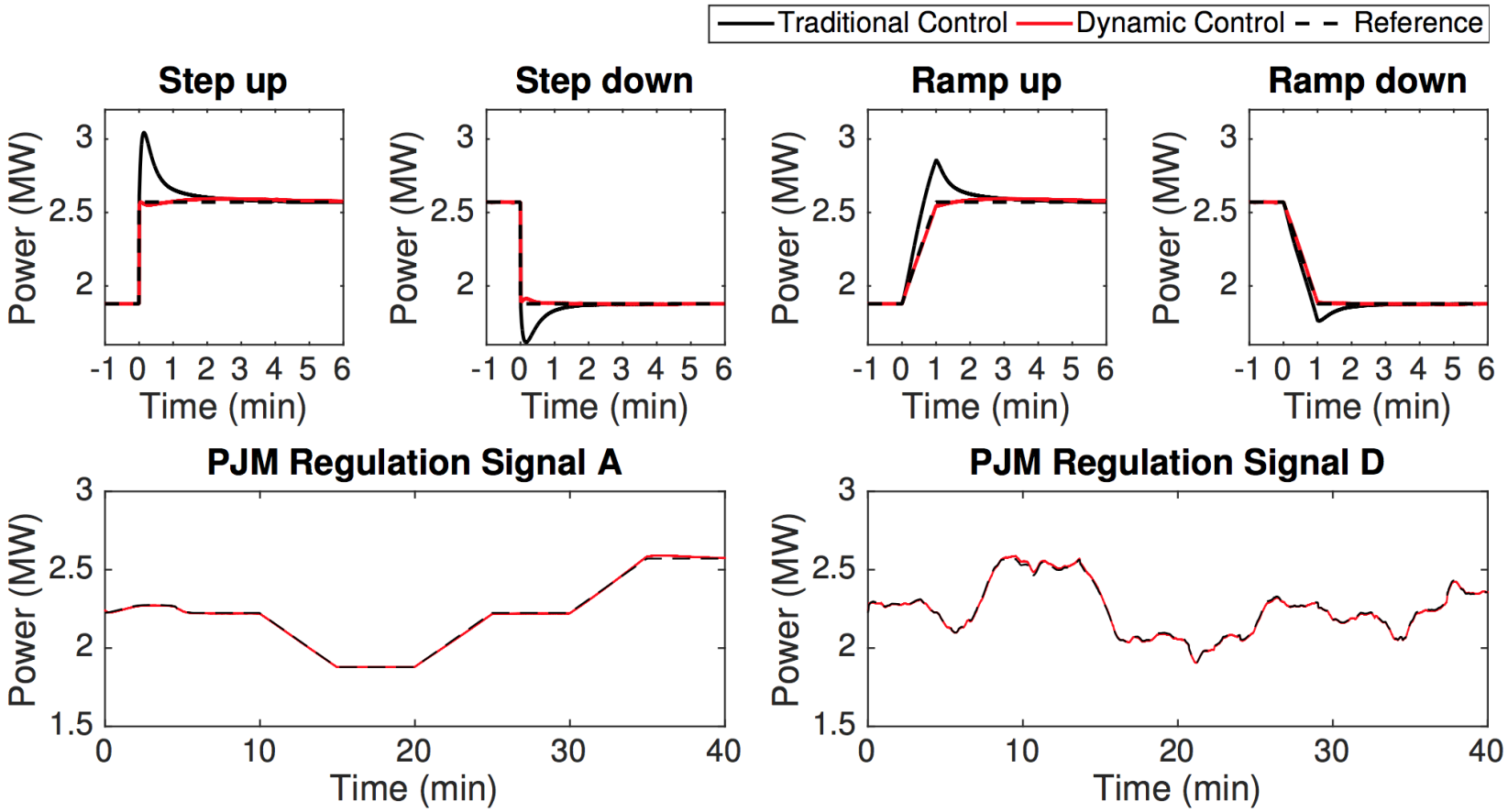


- Overshoot caused by inertial effects
- Wind does not slow down instantaneously to change in thrust
- Results in large initial change in power production

Addressing the transient overshoot

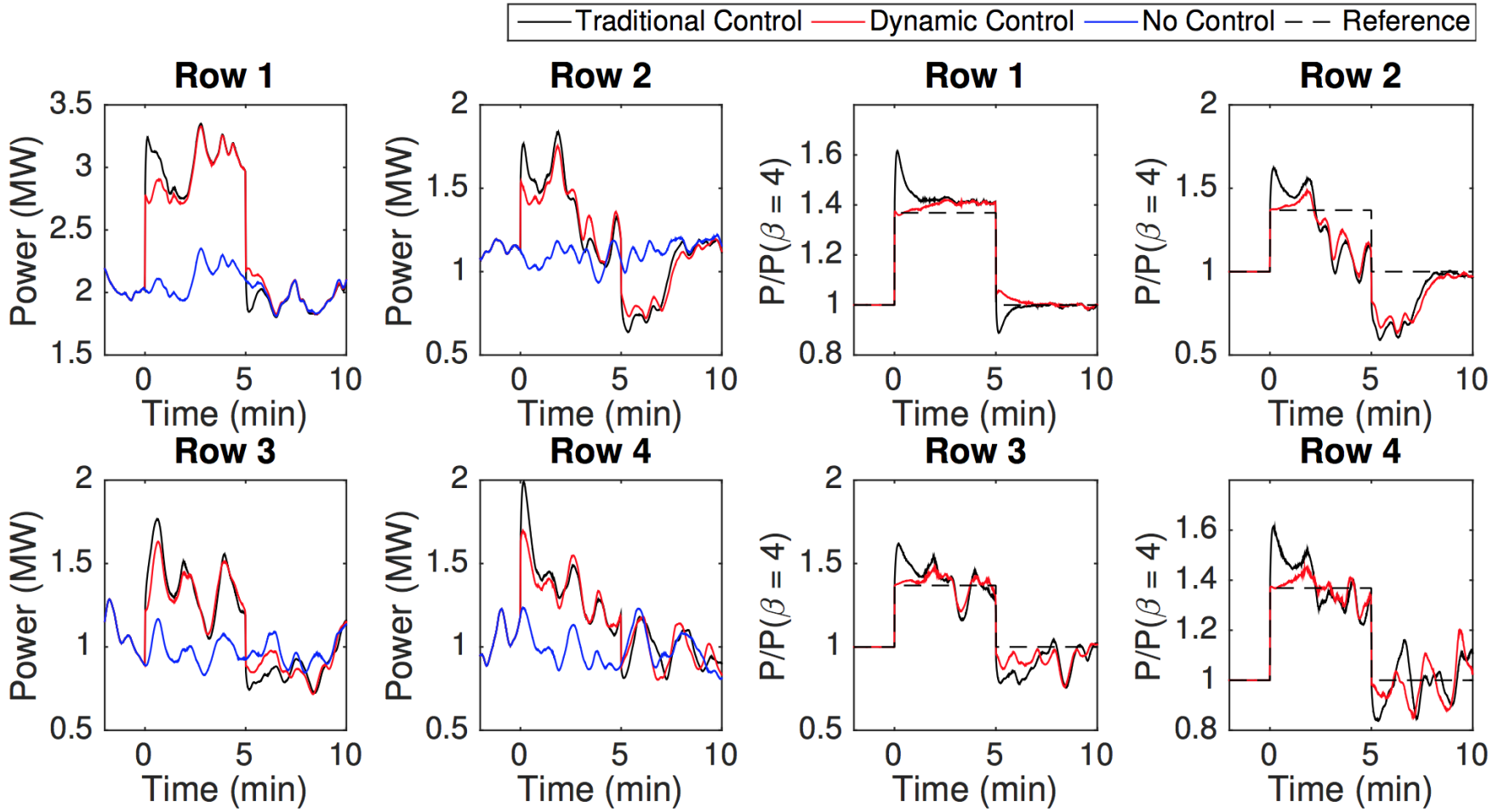
- A linear model is developed from simulated step changes in pitch
- Curve fits used to identify coefficients for model
- Model used to determine needed pitch angle to track curve

Uniform inflow results:



Addressing the transient overshoot

Turbulent inflow results:



Conclusions and future work

Conclusions:

- Wind farms can provide ancillary services, such as secondary frequency regulation
- Current traditional controls that use power coefficient curves do not consider transient aerodynamic effects or turbine interactions
- Large-eddy simulations combined with actuator line model provide test bed to develop more advanced controls
- Transient overshoot can be overcome by using a simple linear plant model

Future work:

- Adjust expected power based on turbulent inflow
- Control farm power by accounting for turbine wake interactions

Questions/Comments

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