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Wind Farm Control Concepts

Supervisory Wind Farm Control Strategy

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Industrial Systems and Control

EWEA 2011

SEVENTH FRAMEWORK
PROGRAMME

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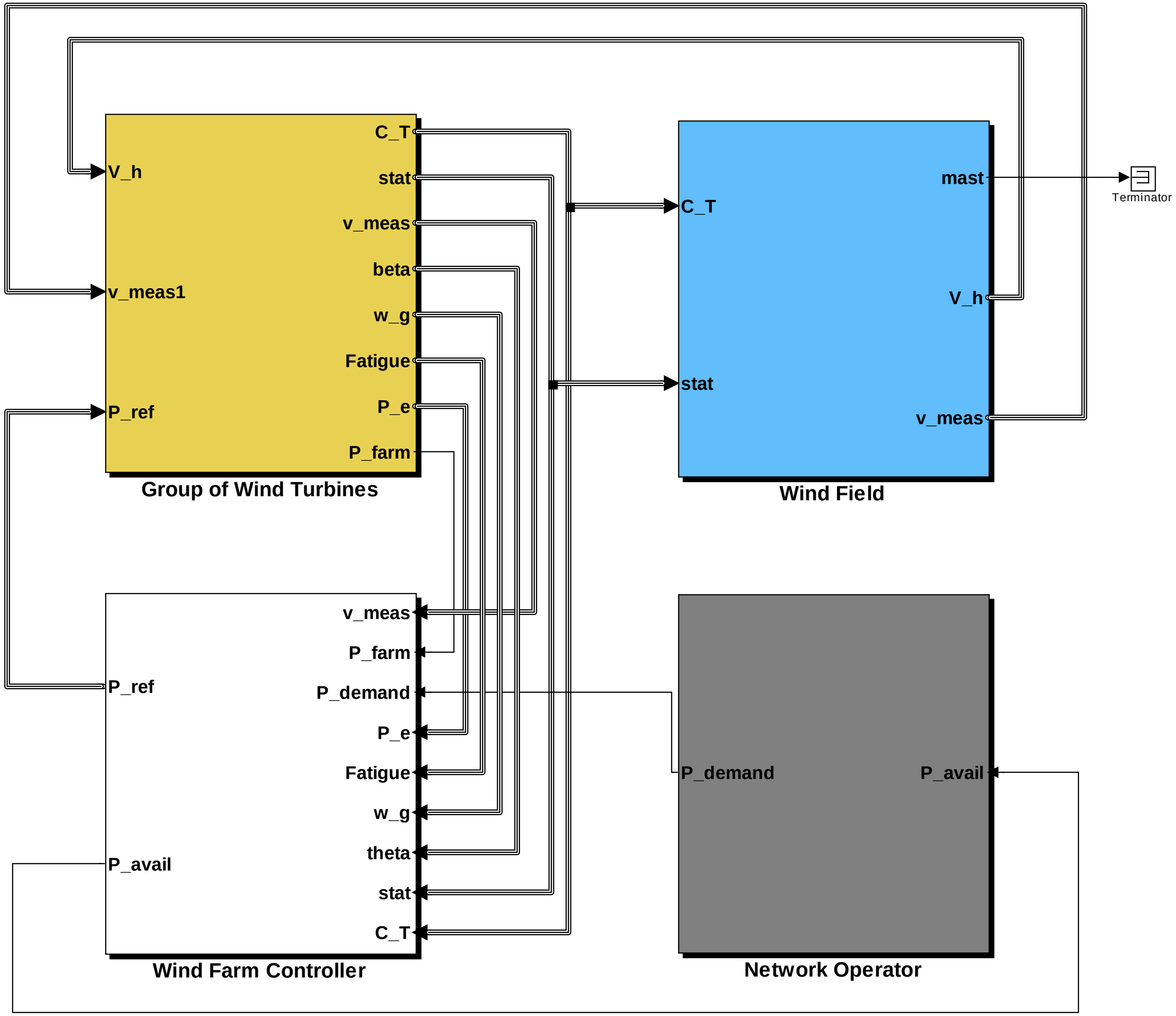
Outline of Presentation

- Introduction
- Control strategy
    - ❒ Selection and development
- Simulation results
- Summary

Introduction

- Control objectives
  - ❐ Track farm active power demand
  - ❐ Minimise Wind Turbine (WT) fatigue load
  - ❐ Continuous control, not on-off
- MPC-based strategy
  - ❐ Track record in large systems

System Structure



Review Summary

- Farm-control work in research stage
  - ❒ Based on simulation models of small WFs
    - ➢ No evidence of effectiveness & scalability to large WFs
- Exception: PI strategy used in Horns Rev WF
- Fatigue loads not considered in WT power ref
  - ❒ Exception: de Almeida et al. work based on optimisation
    - ➢ Fatigue load different from AEOLUS proposal
      - On/off switching i.l.o. continuous load variations
- Few address nonlinearity

Controller Requirements

- Robustness
  - ❒ Wind variations
- Scalability
  - ❒ Design procedure independent of farm size
- Algorithm flexibility
  - ❒ Farm parameters (e.g. no. of WTs, dimensions)
- MPC meets general requirements

Supervisory Control System

1. Nominal control - ISC
   - Obtain optimal distribution of WF power reference based on wind flow model
   - Adapt to ‘slow’ changes in wind farm operating conditions
     - 5-10 s sample time
2. Reconfiguration extension – Univ. of Zagreb
   - Minimize impact of disturbances on wind farm behaviour
     - Keep wind farm behaviour as close as possible to optimal
   - Actively compensate disturbances related to faster dynamics inherent to wind farm

Model Linearisation

- Wind turbine
  - Use models developed by Univ. of Zagreb
    - (Re-)Sampled to 10 seconds
- Wind field
  - Simpler nonlinear model than WT
    - Original field model; later more complex
  - Affine model + delay
    - Gain estimated by sensitivity analysis
    - Delay = distance/wind_speed

MPC Formulation

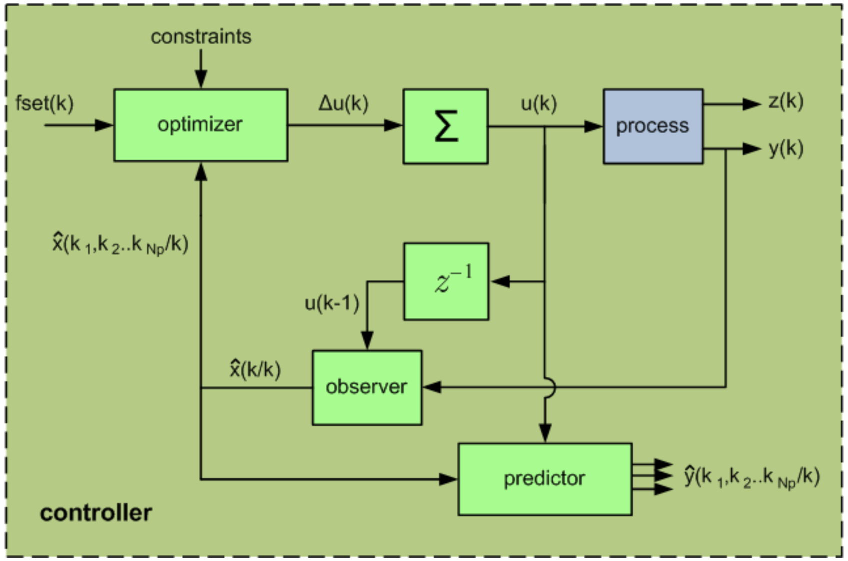
- Standard GPC state-space formulation
  - E.F. Camacho & C. Bordons, *Model Predictive Control* (2nd Edition), Springer-Verlag, 2004

- Incremental model realization

$$\begin{bmatrix} \mathrm{x(t+1)} \\ \mathrm{u(t)} \end{bmatrix} = \begin{bmatrix} \mathrm{A} & \mathrm{B} \\ 0 & \mathrm{I} \end{bmatrix}\begin{bmatrix} \mathrm{x(t)} \\ \mathrm{u(t\text{-}1)} \end{bmatrix} + \begin{bmatrix} \mathrm{B} \\ \mathrm{I} \end{bmatrix}\mathrm{Du(t)},$$

$$\mathrm{y(t)} = \begin{bmatrix} \mathrm{C} & 0 \end{bmatrix}\begin{bmatrix} \mathrm{x(t)} \\ \mathrm{u(t\text{-}1)} \end{bmatrix}$$

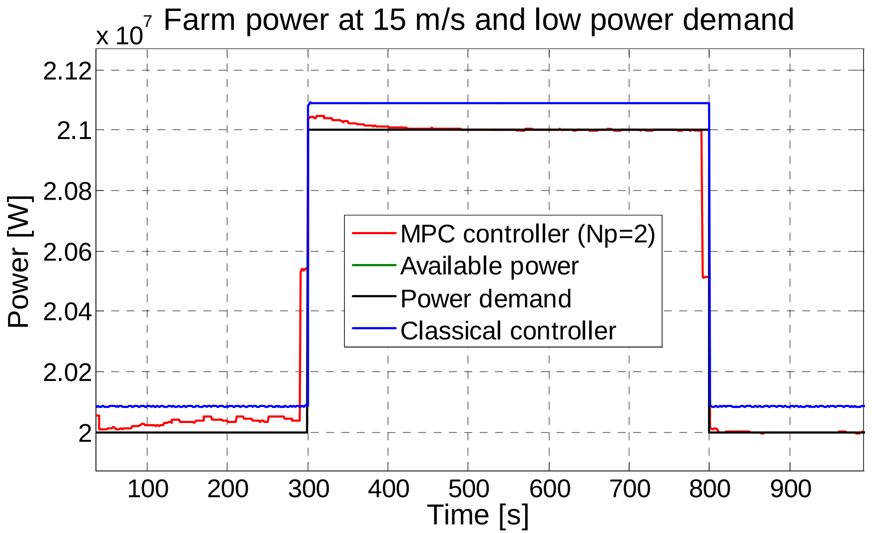
- Time-varying KF for state estimation enhanced with GPC prediction matrices to produce future output signals
  - M. J. Grimble and P. Majecki, “State-space approach to nonlinear predictive generalized minimum variance control”, *International Journal of Control*, 2010

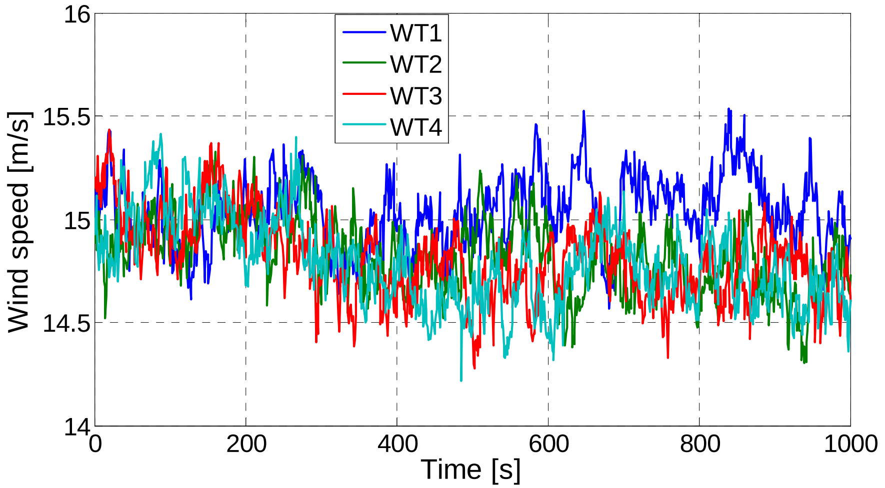


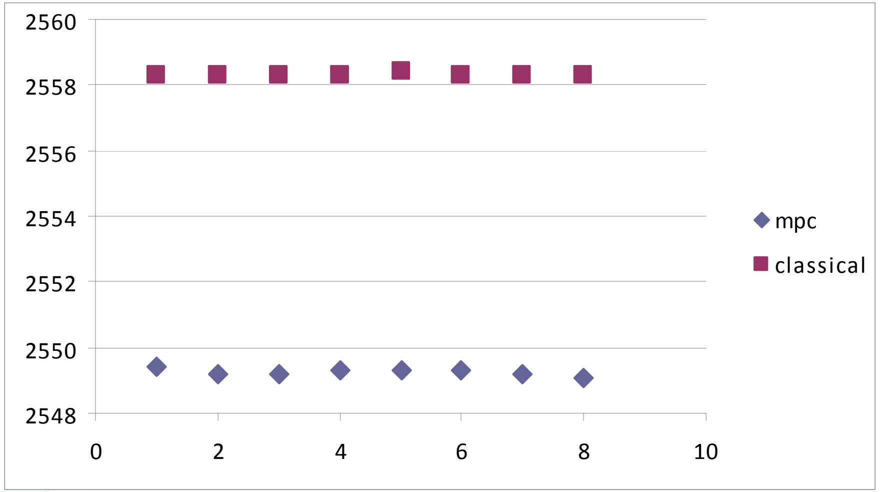
- Quadratic cost function →QP solver online

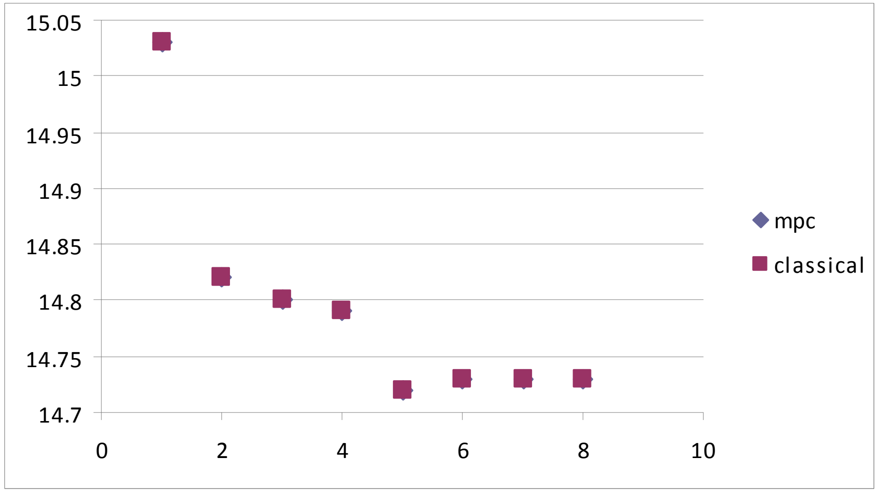
$$\mathrm{J} = (y(t) - \mathrm{R_{fut}})^T Q_w (y(t) - \mathrm{R_{fut}}) + \Delta\mathrm{u(t)}^{\mathrm{T}} \lambda_w \Delta\mathrm{u(t)}$$

MPC at High Wind Speed
Low Power Demand

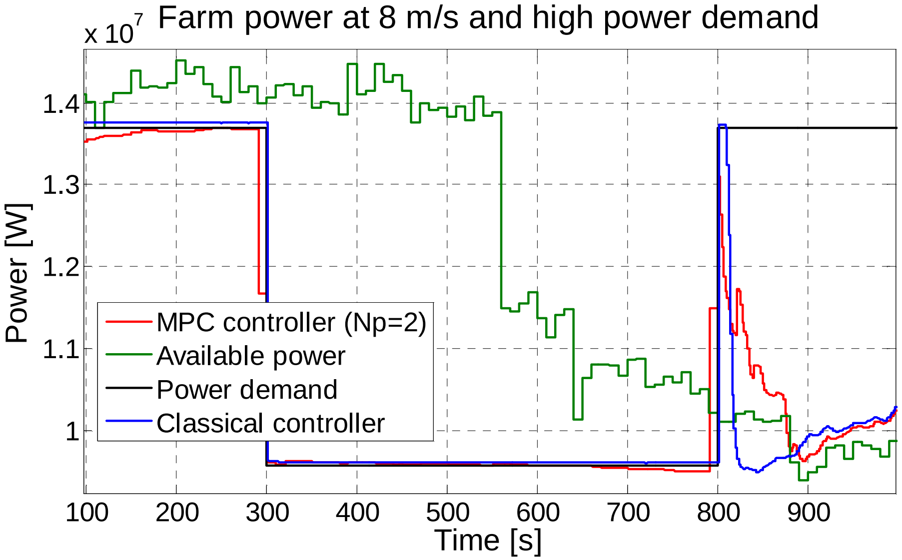

Farm power at 15 m/s and low power demand

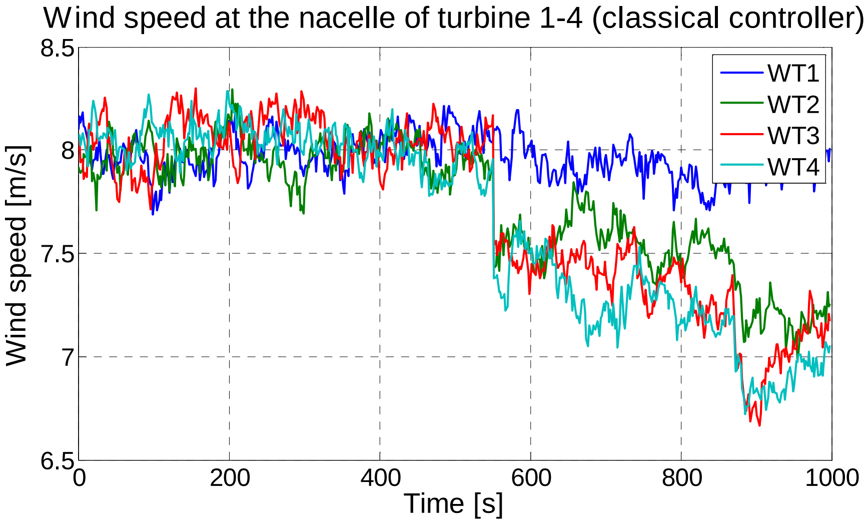

Wind speed at the nacelle of turbine 1-4 (mpc)

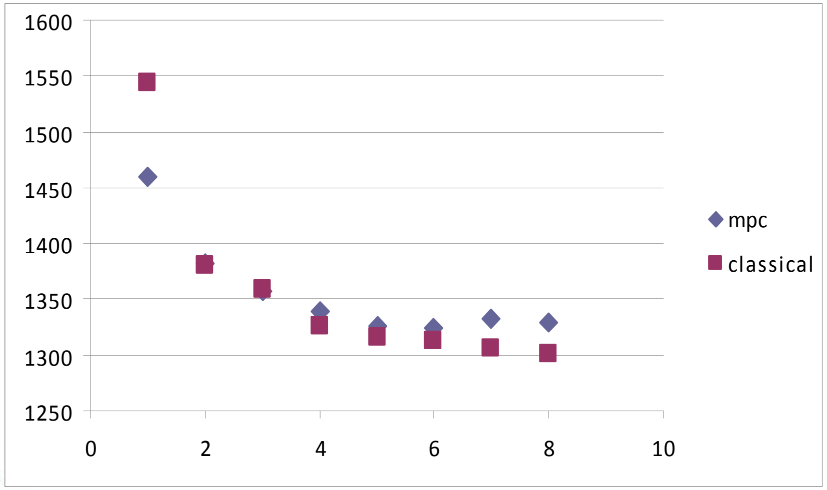


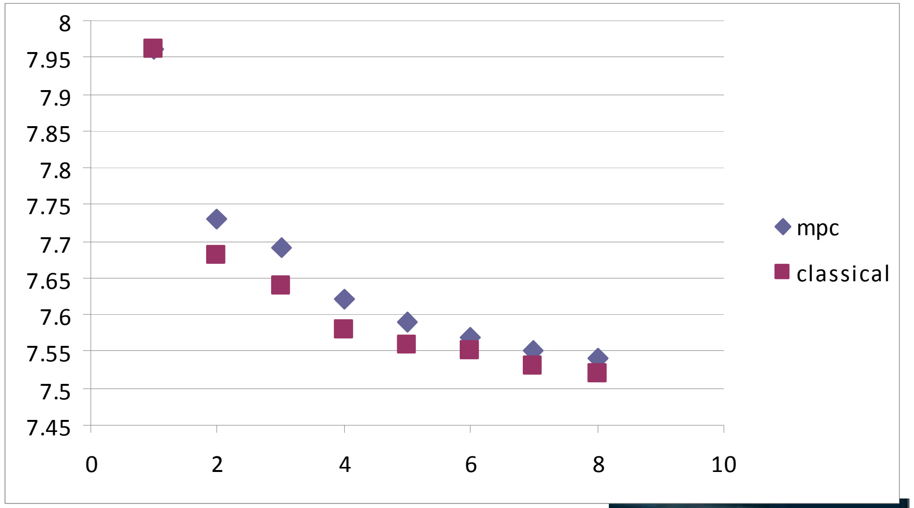


MPC vs. Base at Low Wind Speed High Power Demand

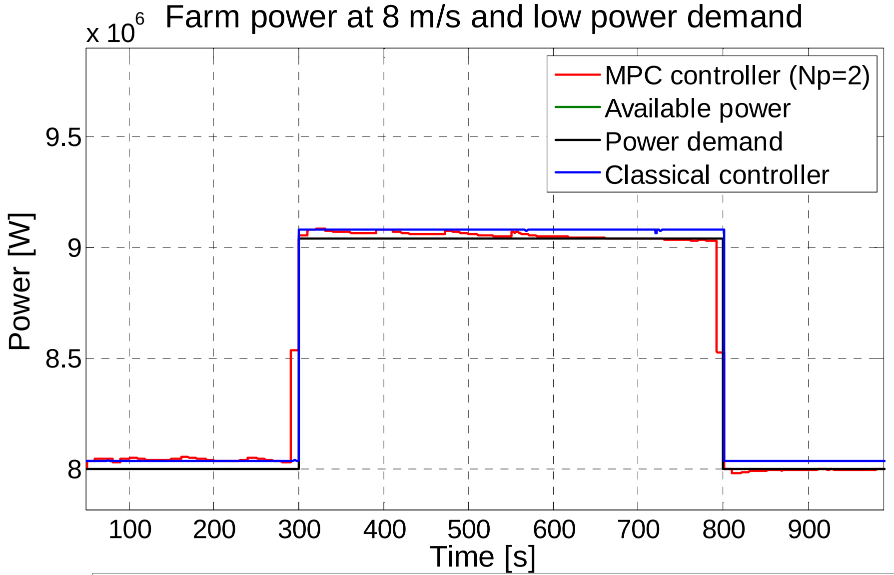

Farm power at 8 m/s and high power demand

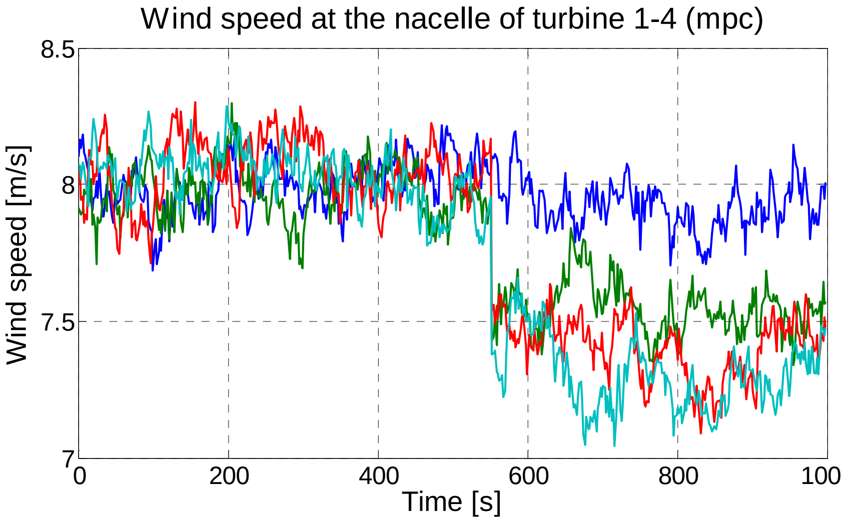

Wind speed at the nacelle of turbine 1-4 (classical controller)

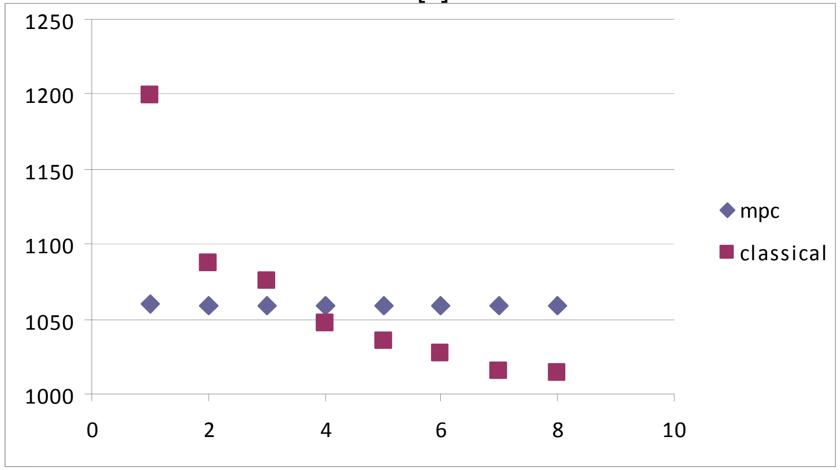


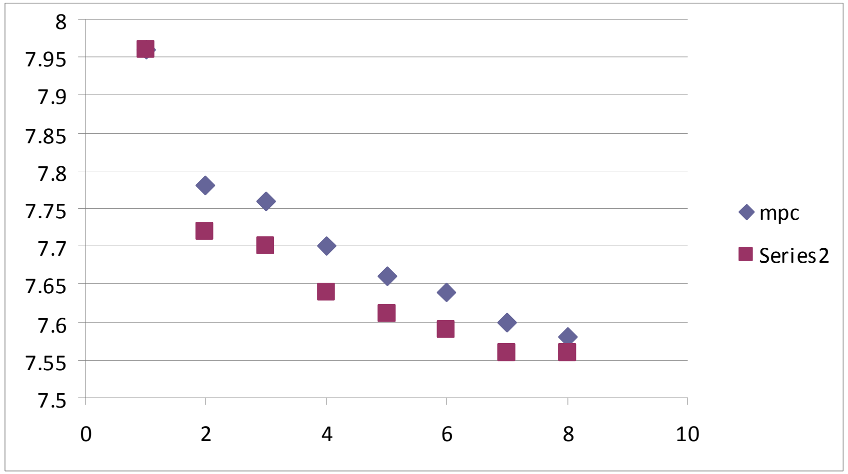


MPC vs. Base at Low Wind Speed Low Power Demand


Farm power at 8 m/s and low power demand


Wind speed at the nacelle of turbine 1-4 (mpc)





RMS Reductions

High wind speed	High Pfarm	Low Pfarm
Total cost	0.50 %	1.00 %
Relative power error	42.50 %	43.00 %
Relative Mtow (RMS)	0.21 %	0.31 %
Relative Mtow (STD, 10-sample window)	-0.23 %	-0.22 %

Low wind speed	High Pfarm	Low Pfarm
Total cost	2.03 %	2.70 %
Relative power error	10.77 %	50.48 %
Relative Mtow (RMS)	1.40 %	3.35 %
Relative Mtow (STD, 10-sample window)	13.36 %	36.08 %

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Questions?

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