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Wind Farm Control Concepts

Supervisory Wind Farm Control Strategy

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Industrial Systems and Control

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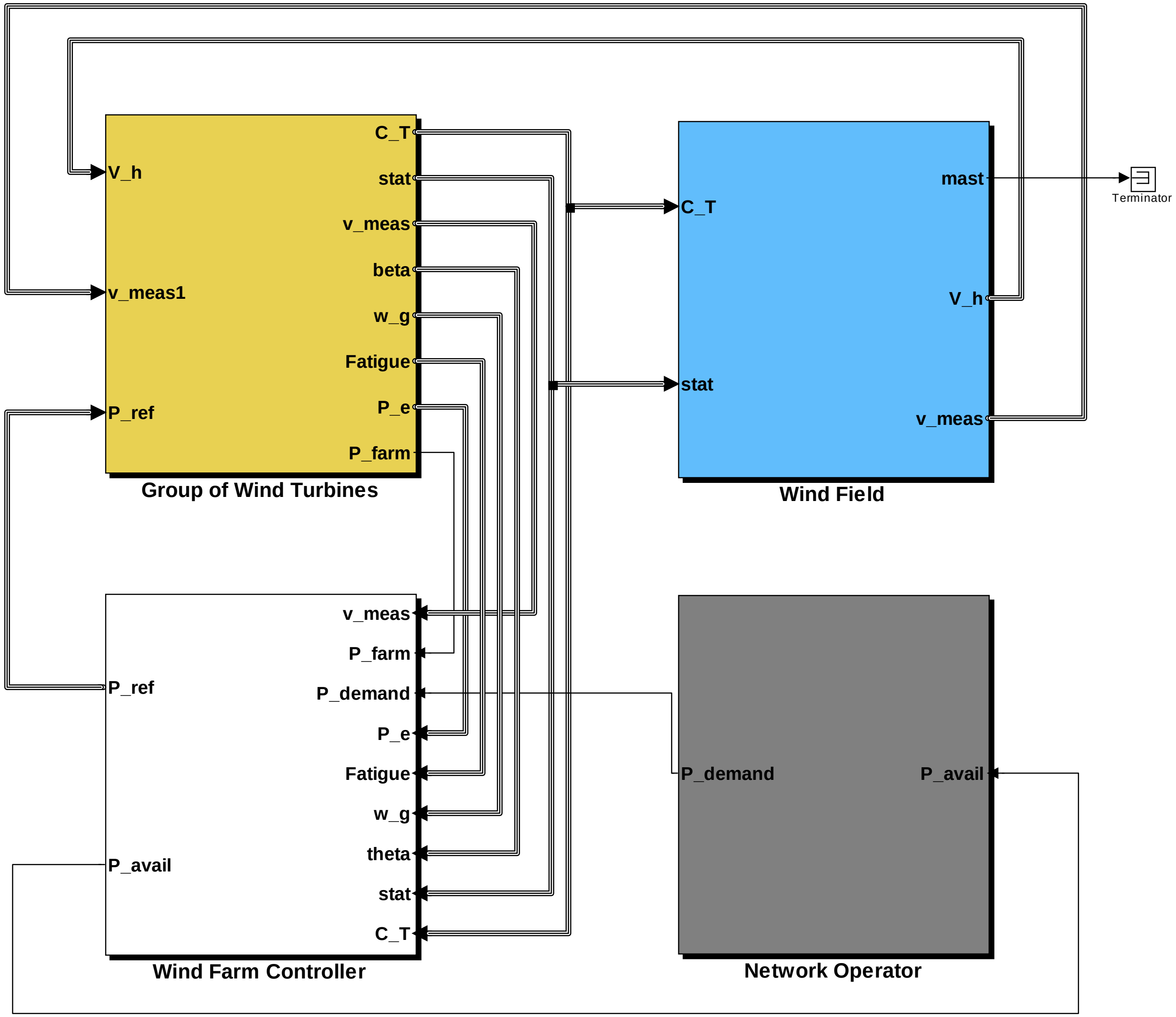
Outline of Presentation

- 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



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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

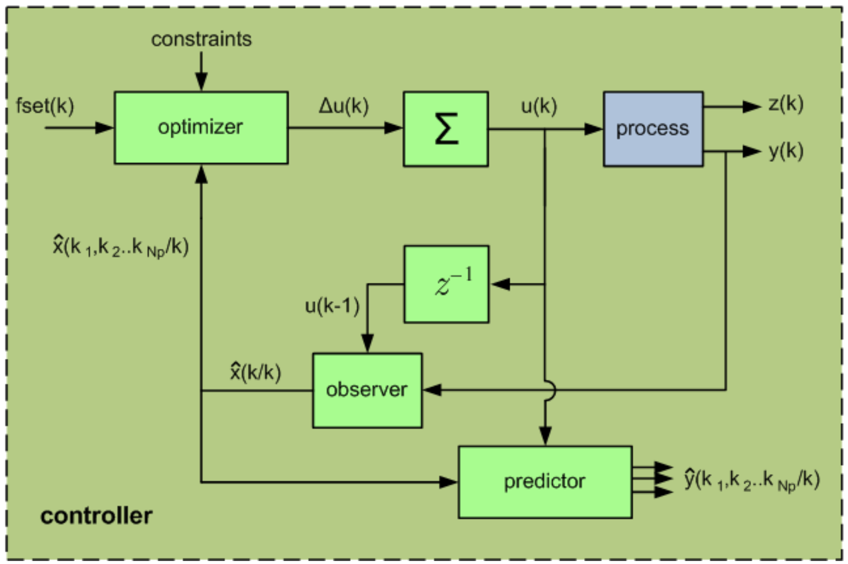
- Standard GPC state-space formulation
  - E.F. Camacho & C. Bordons, *Model Predictive Control* (2nd Edition), Springer-Verlag, 2004

- Incremental model realization

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

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

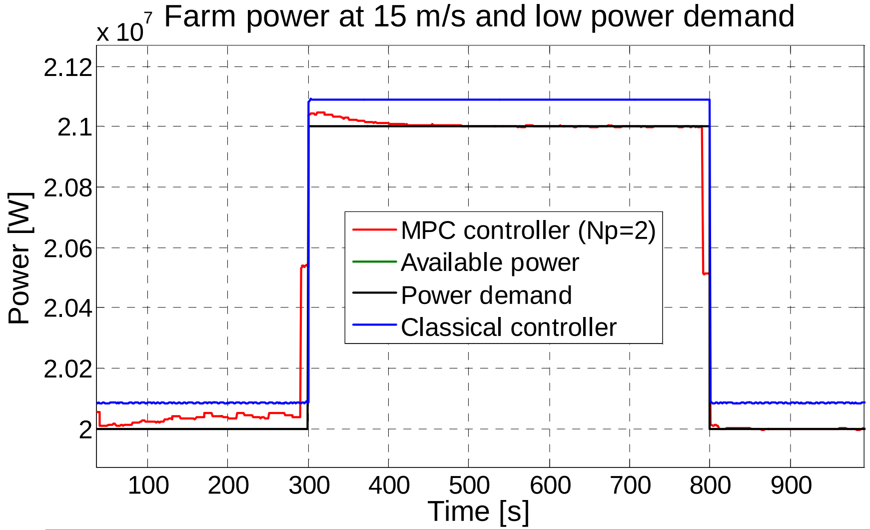
- Time-varying KF for state estimation enhanced with GPC prediction matrices to produce future output signals
  - M. J. Grimble and P. Majecki, "State-space approach to nonlinear predictive generalized minimum variance control", *International Journal of Control*, 2010

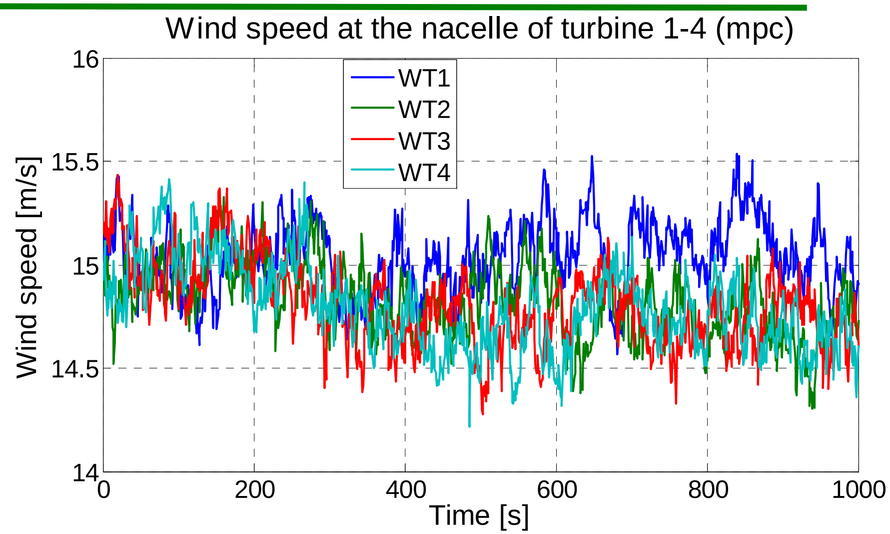


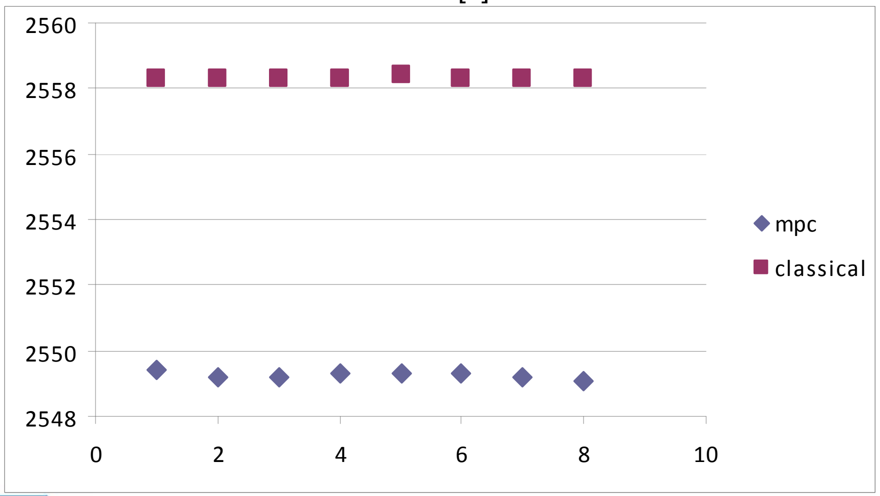
- Quadratic cost function →QP solver online

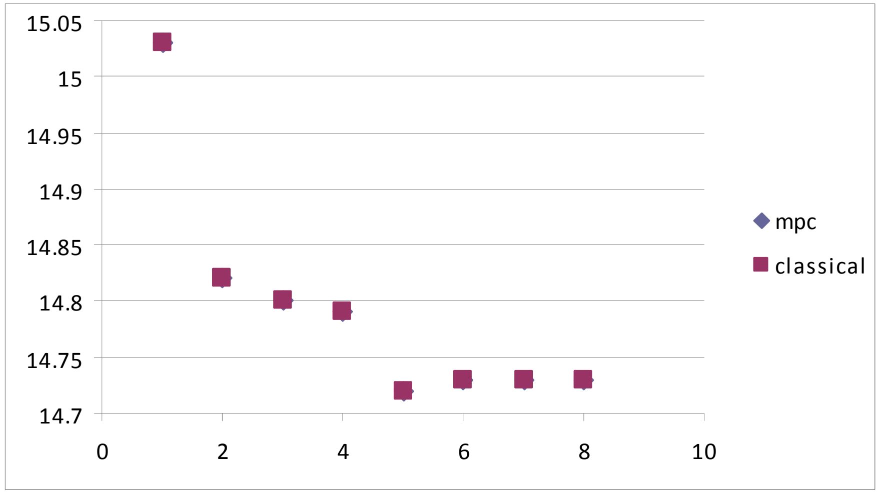
$$J = (y(t) - R_{fut})^T Q_w (y(t) - R_{fut}) + \Delta u(t)^T \lambda_w \Delta u(t)$$

MPC at High Wind Speed Low Power Demand

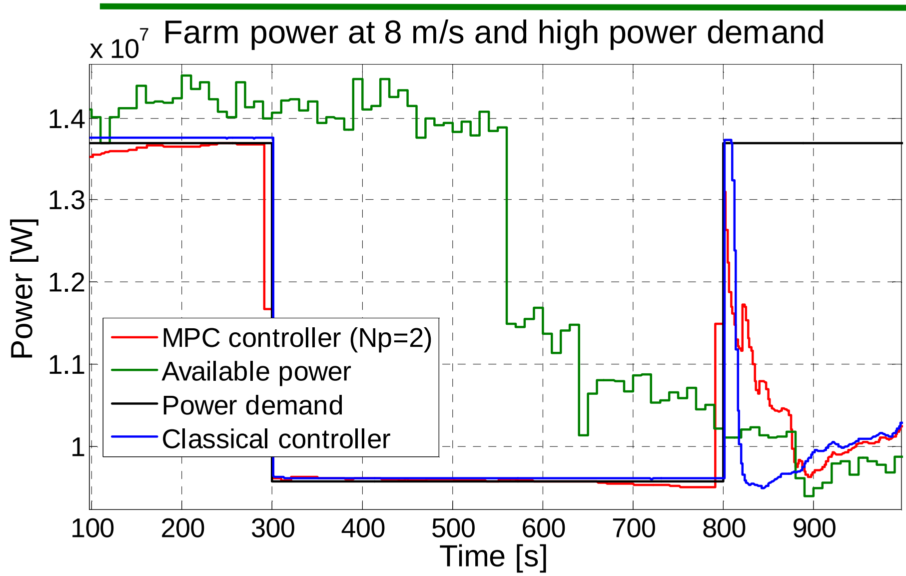


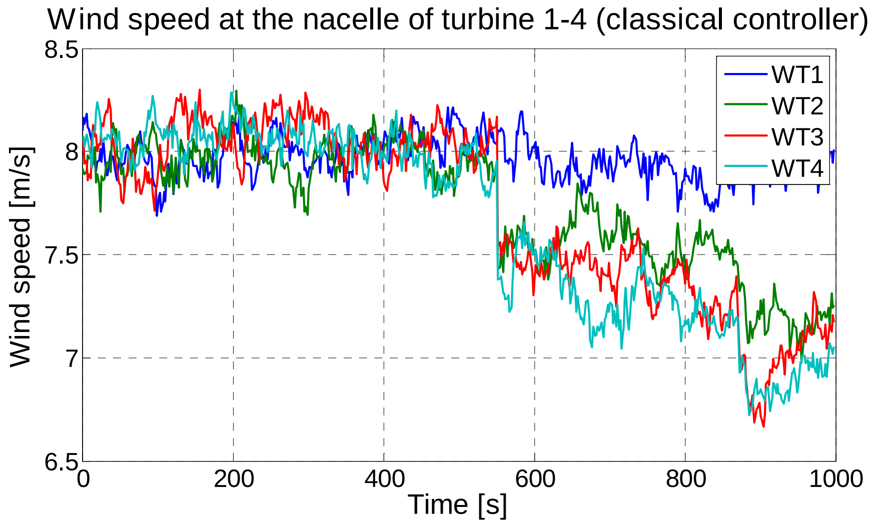


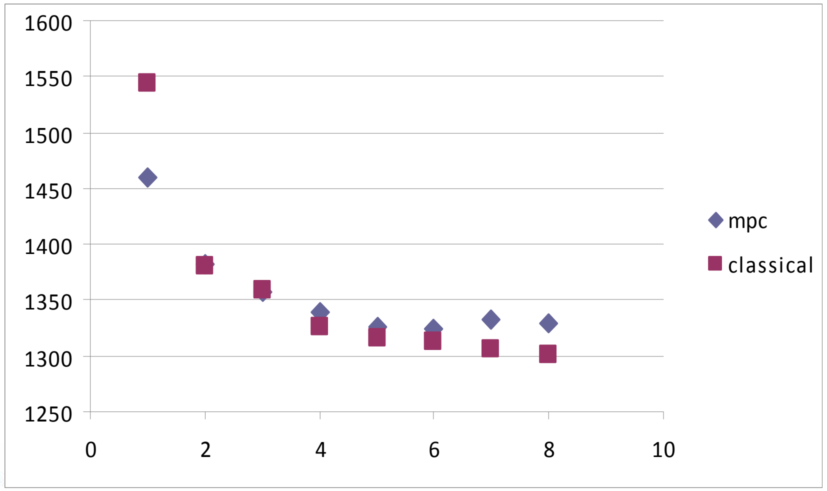


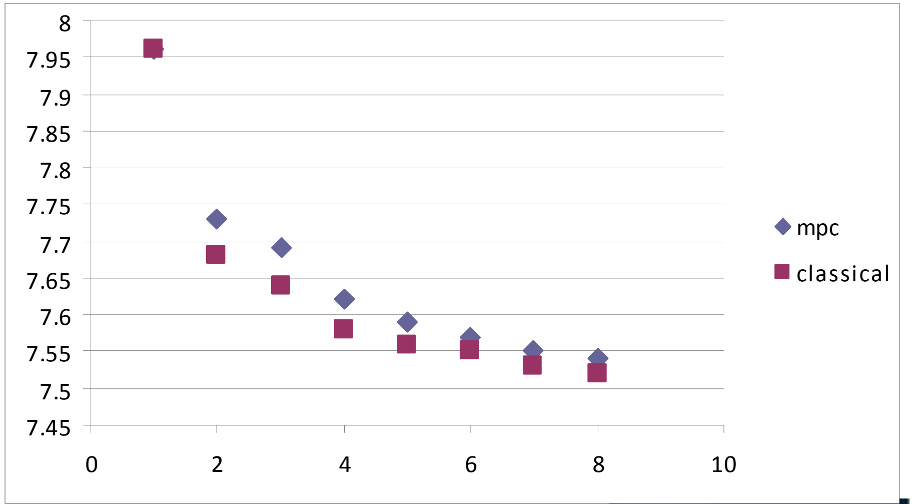


MPC vs. Base at Low Wind Speed High Power Demand









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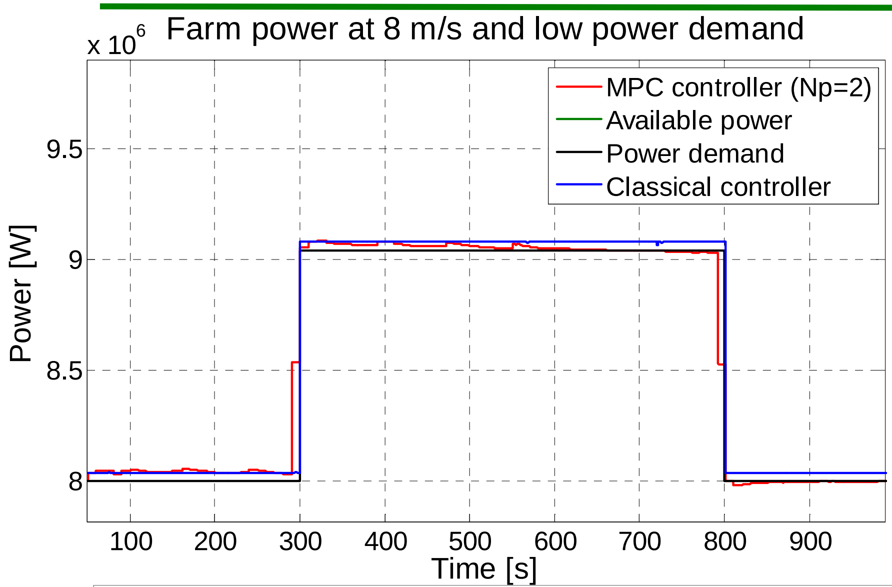

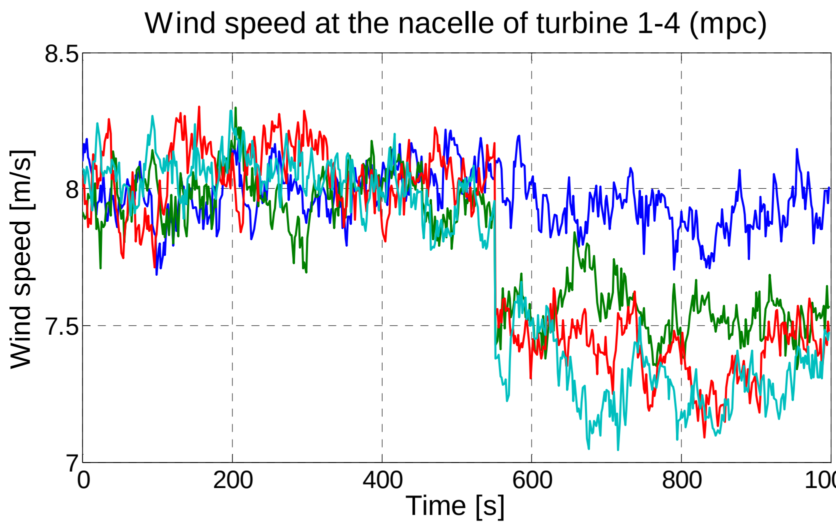

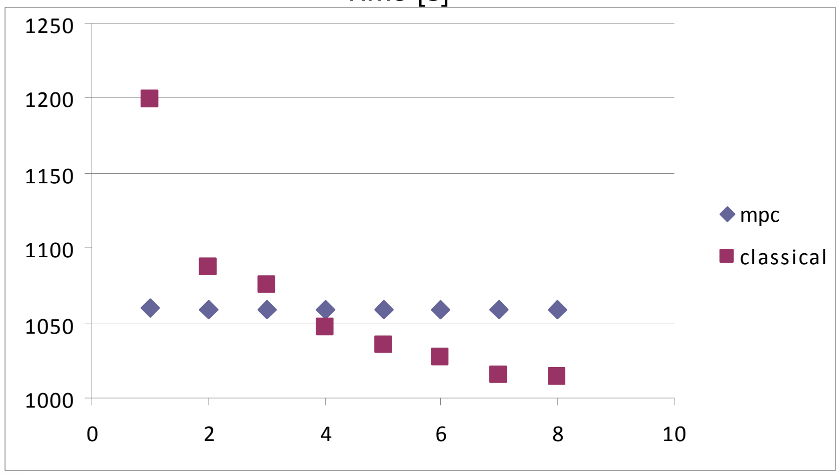

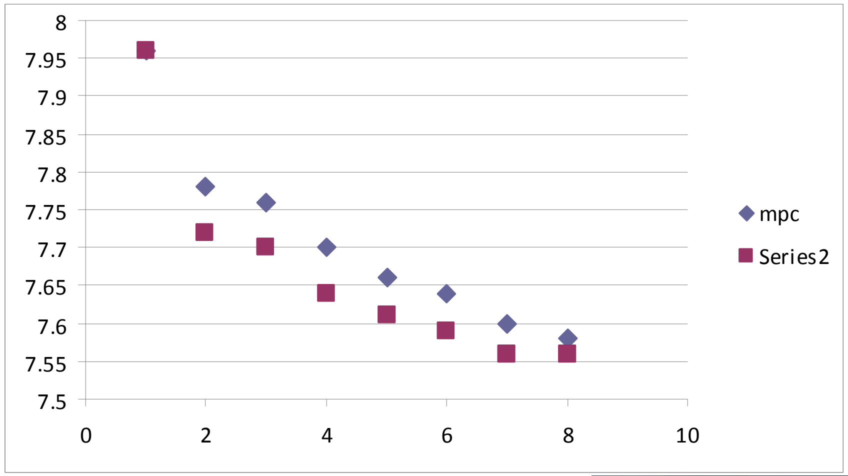

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RMS Reductions

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 %

Questions?

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