

Fast Model Predictive Control



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Discussion Overview



- Models for Fast Model Predictive Control (MPC)
 - Selecting a Model for MPC
 - Subspace Identification (Linear model)
 - Parameter Estimation (Nonlinear model)
- Fast MPC Demonstrations with a 4 Tank Process
 - PID Control
 - Fast Linear MPC
 - Fast Nonlinear MPC
 - Comparison of Control Performance
- Next Generation Modeling and Control Platform

Selecting a Model for Predictive Control



- Many model forms
 - Linear vs. Non-linear
 - Steady state vs. Dynamic
 - Empirical vs. First Principles
- Select the simplest model
 - Accuracy requirements
 - Steady State Gain
 - Dynamics – Time to Steady State
 - Speed requirements
 - PID < Linear MPC < Nonlinear MPC

Continuous Form (SS_c)

$$\dot{x} = Ax + Bu$$

$$y = Cx + Du$$

Discrete Form (SS_d)

$$x[k+1] = A_d x[k] + B_d u[k]$$

$$y[k] = C_d x[k] + D_d u[k]$$

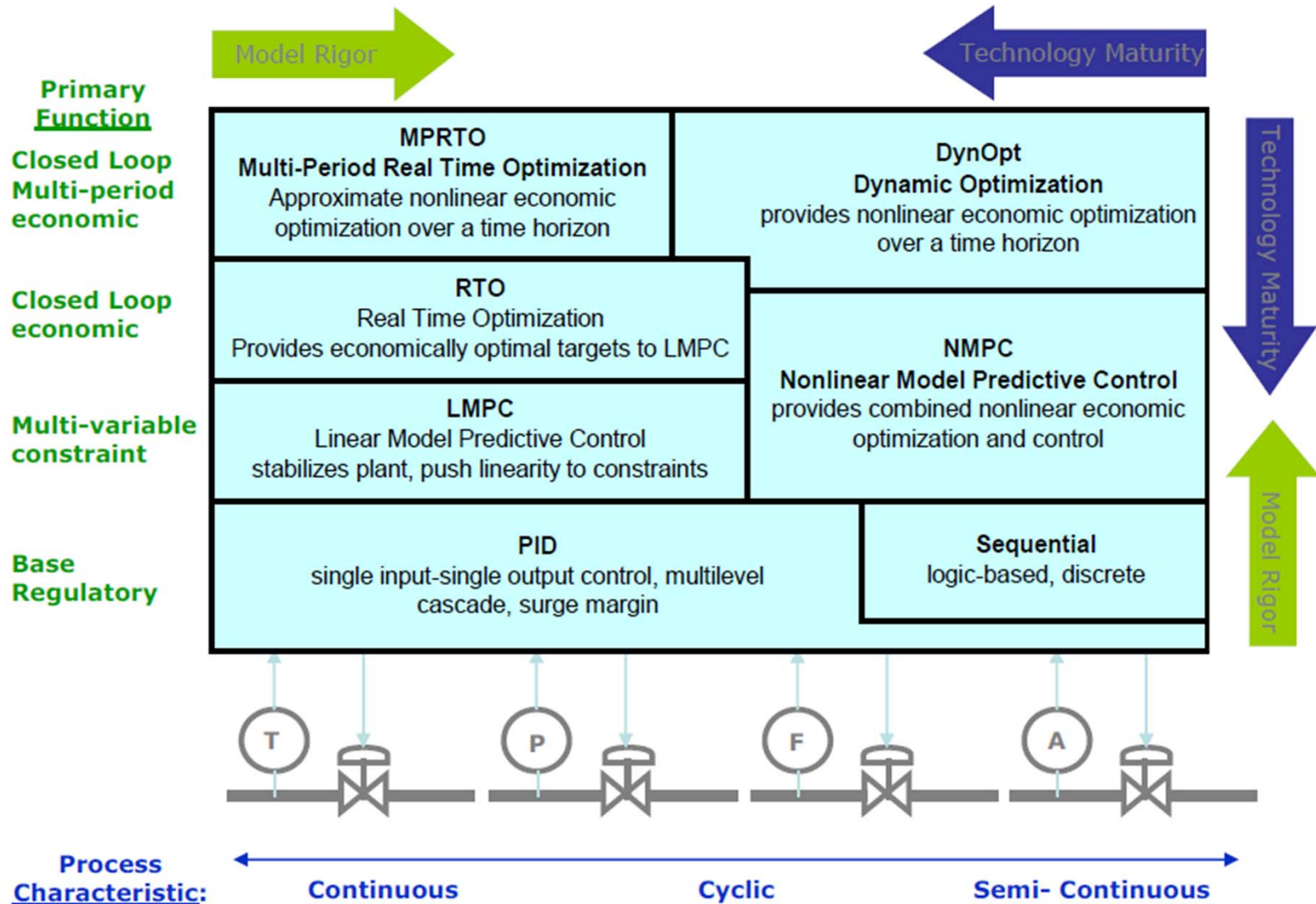
Nonlinear Model

$$0 = f(\dot{x}, x, u, p, d)$$

$$0 = g(x, u, p, d)$$

$$0 \leq h(x, u, p, d)$$

Control Technology Overview



Soderstrom, Hedengren, and Yang, Advanced Process Control in ExxonMobil Chemical Company: Successes and Challenges, AIChE 2010.

Discussion Overview

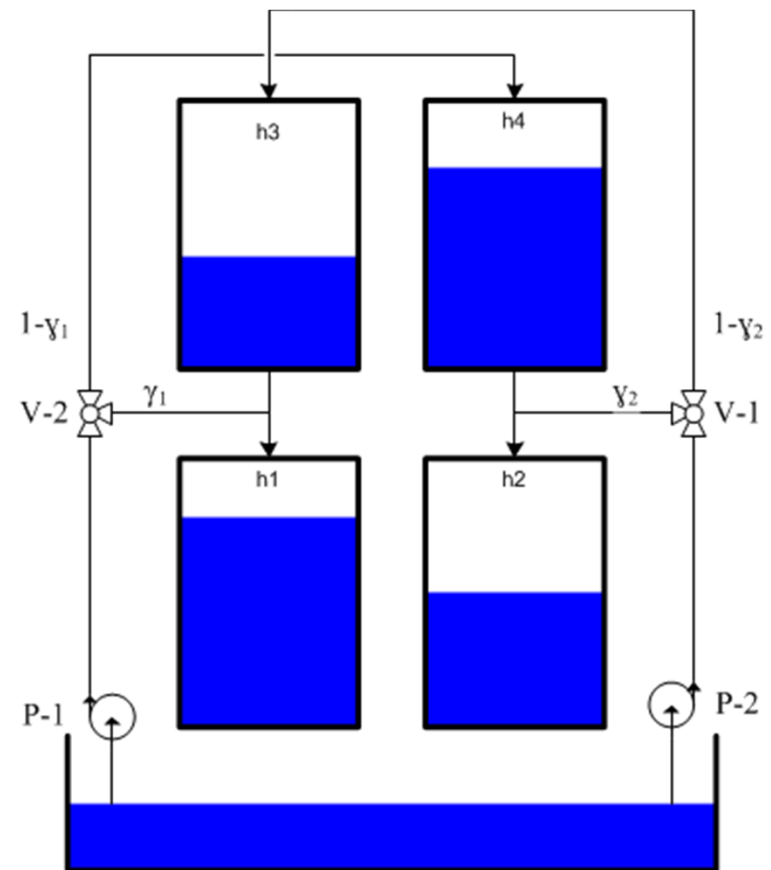


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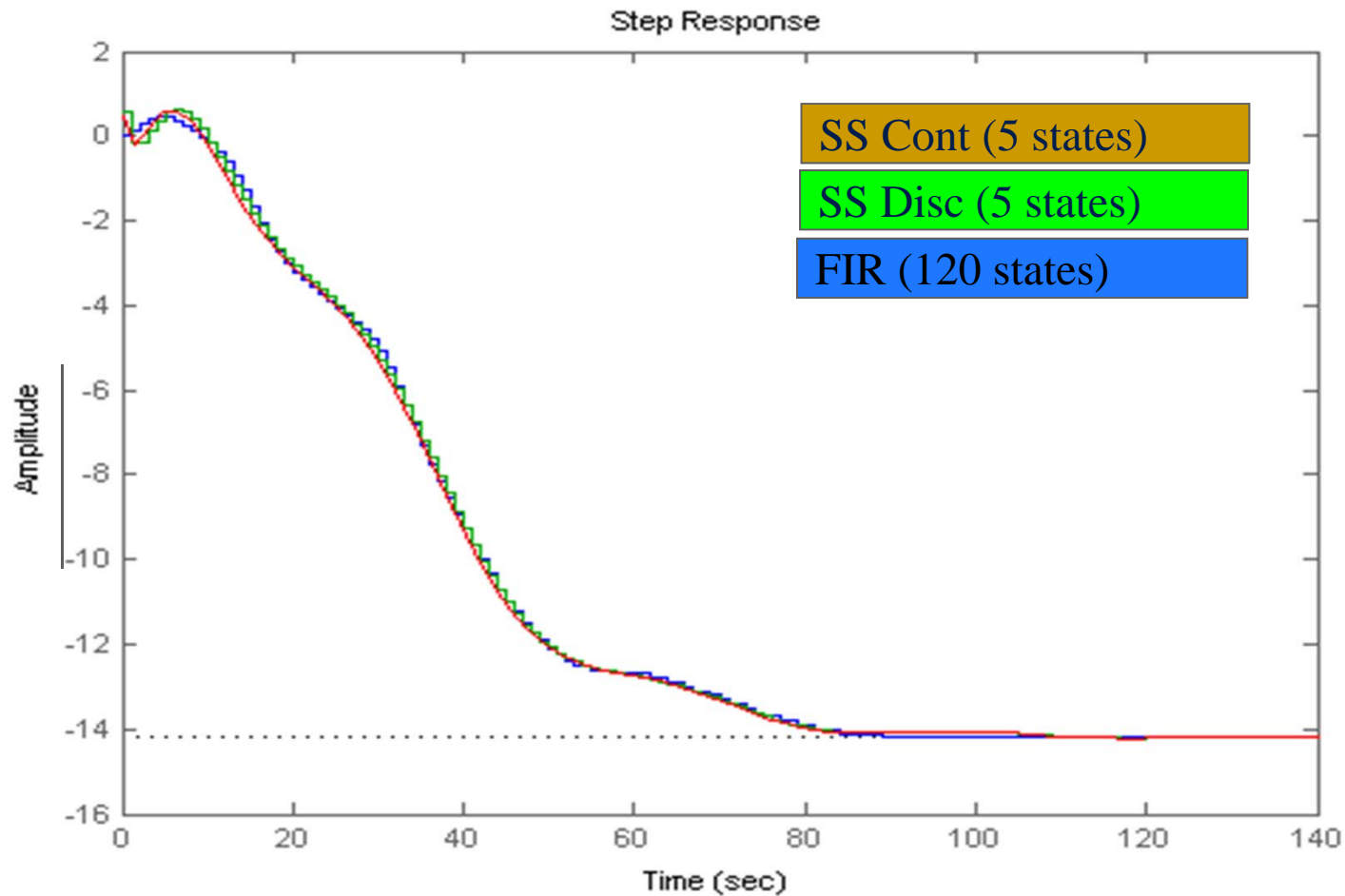


Multivariate 4 Tank Process

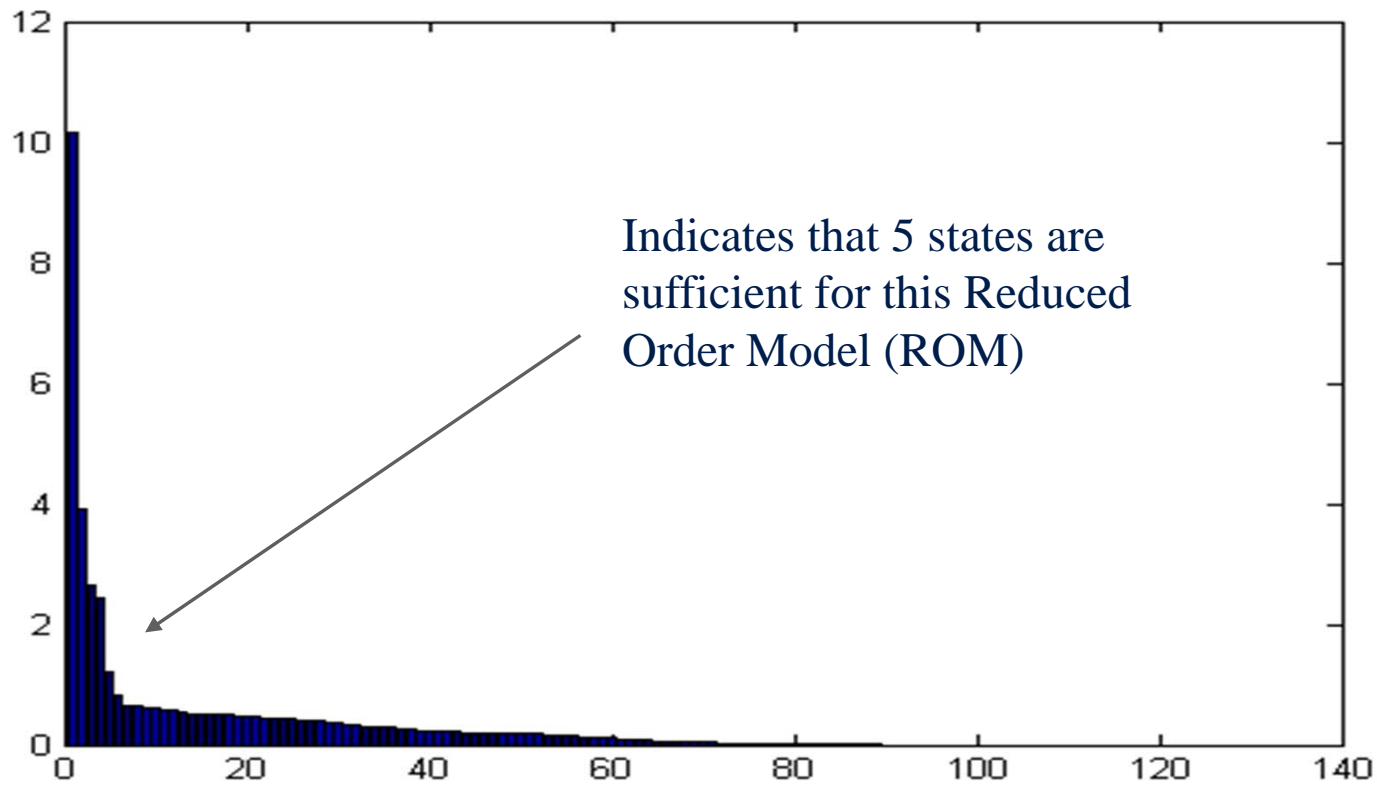
- Multiple Inputs (2)
 - Pump 1 and Pump 2 Voltages
- Multiple Outputs (2)
 - Height in Lower Tanks (1-2) Measured
- Characteristics
 - Highly coupled system
 - May exhibit inverse response
 - Split fractions (γ_1 - γ_2) drastically change system dynamics and steady state behavior



Capture Essential Dynamics with State Space Models



Determine Number of States





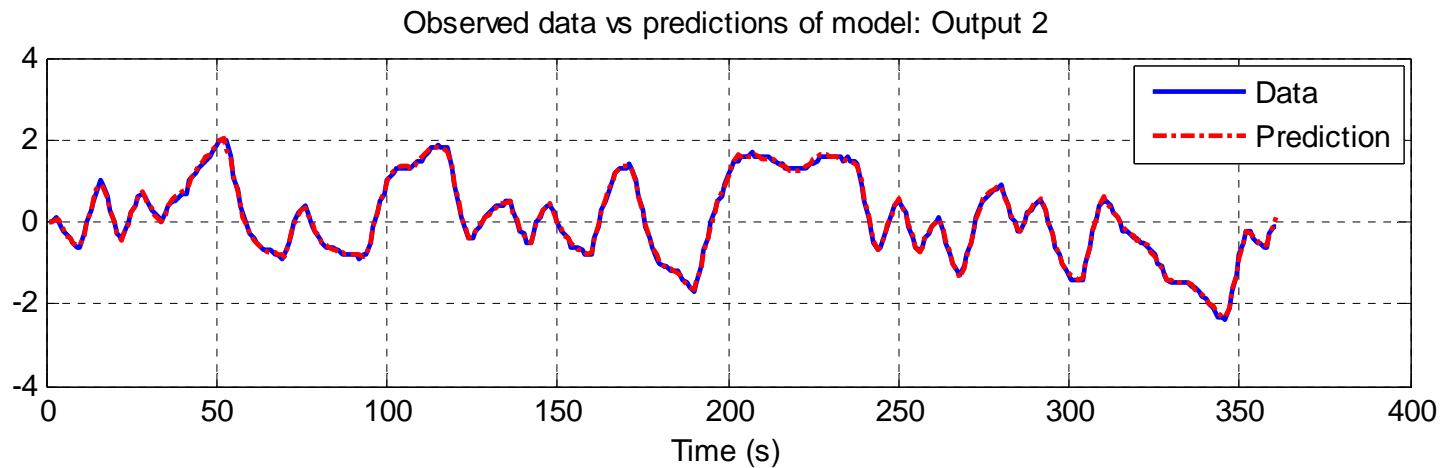
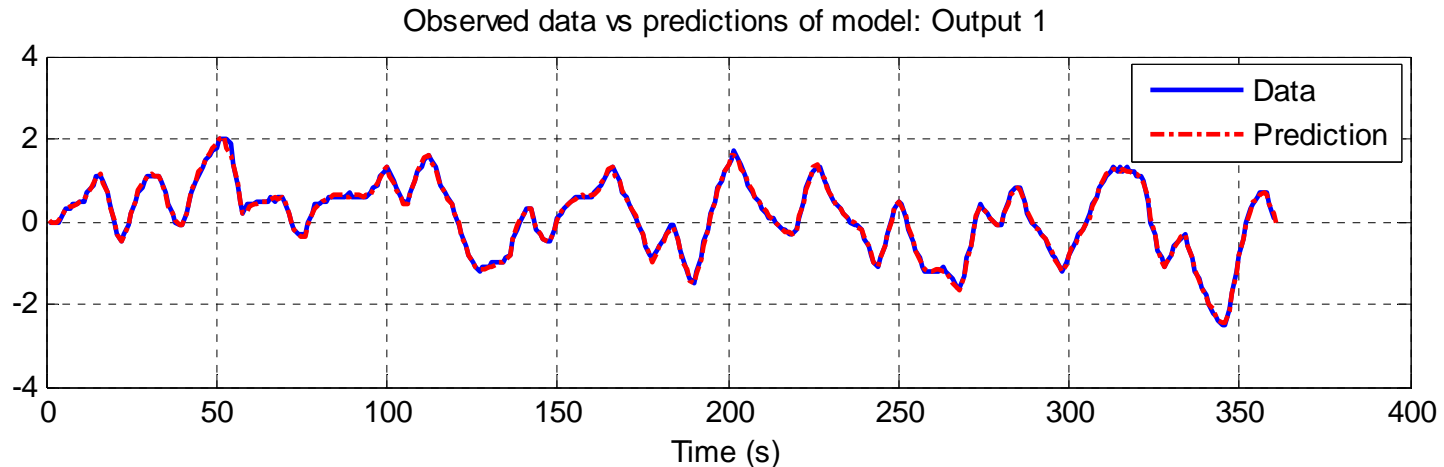
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Linear Model Identification



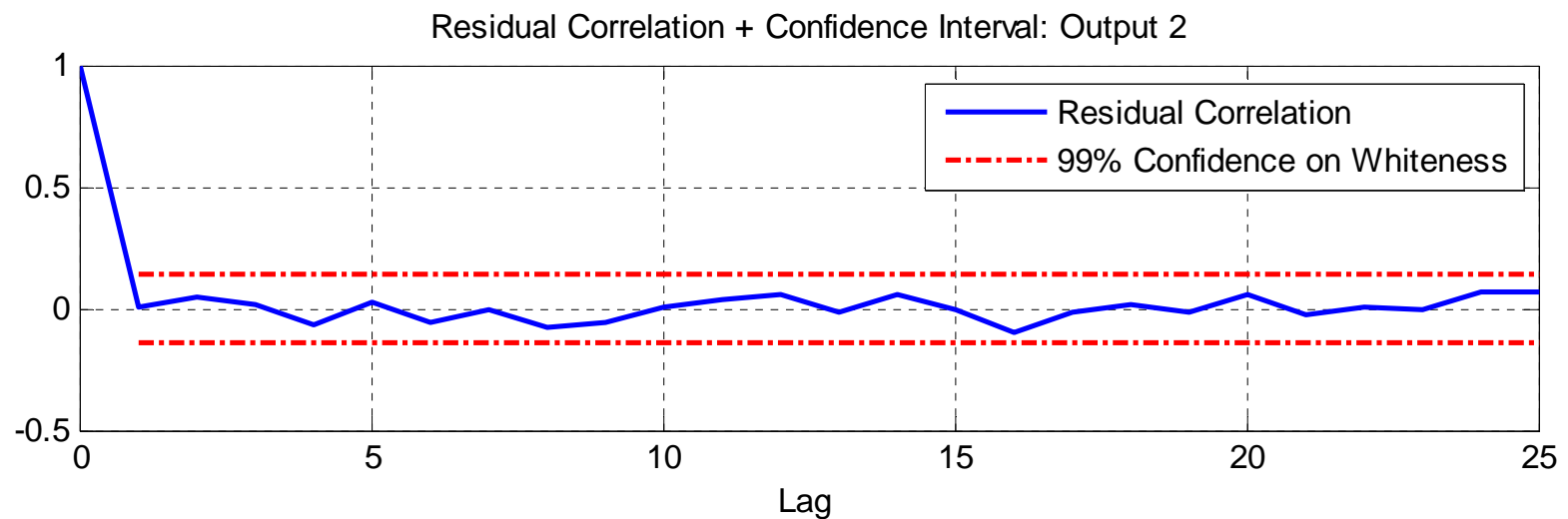
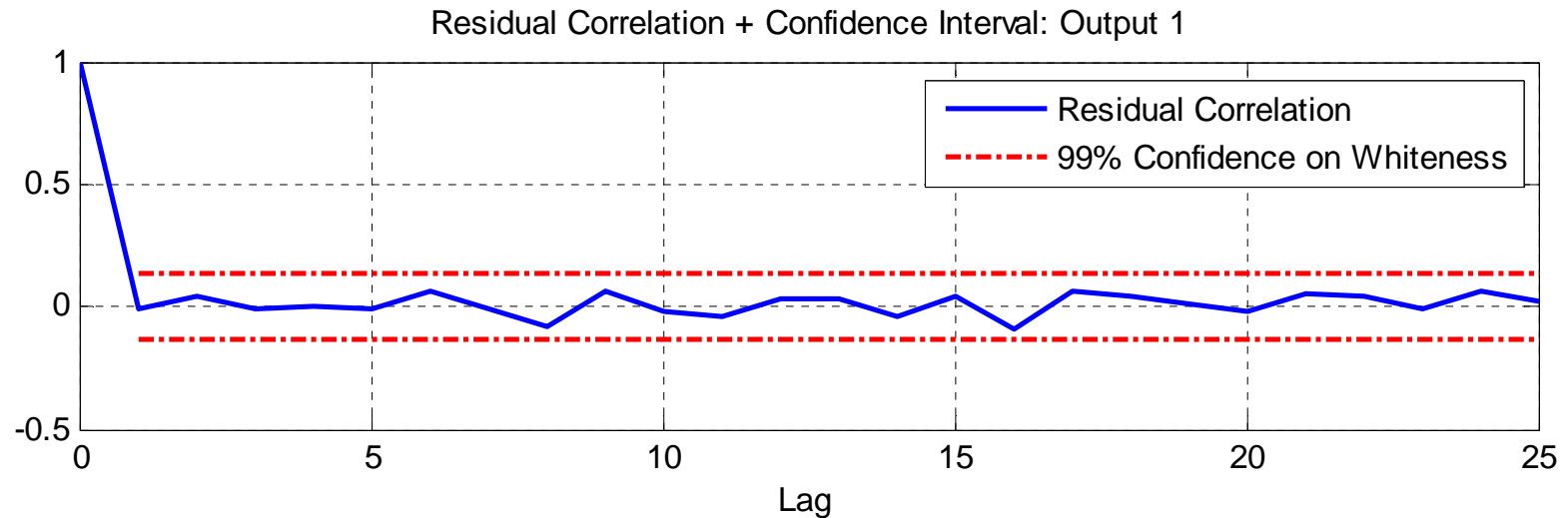
➤ Linear Empirical Model (ARX)



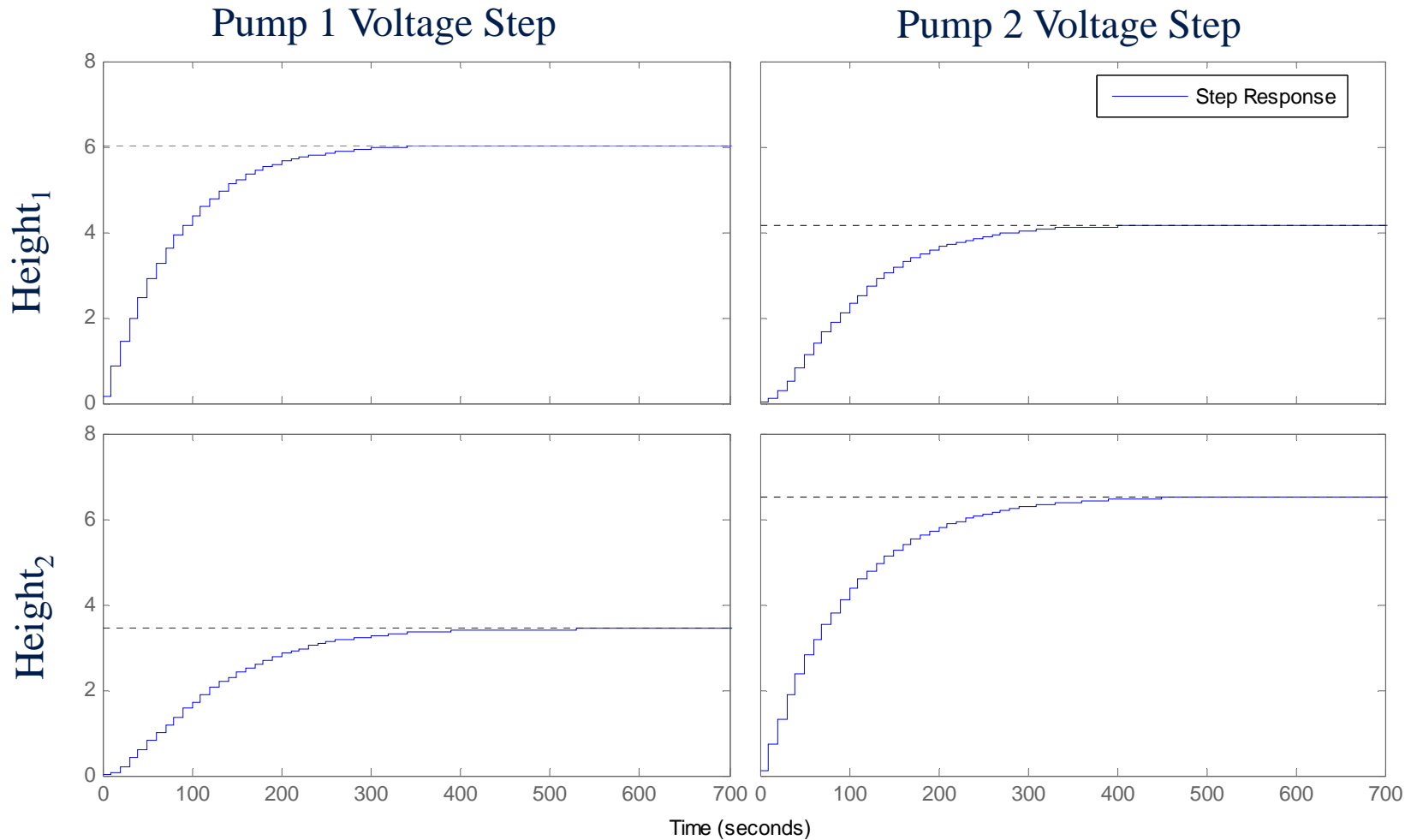
Correlation of Residuals



➤ Residual Whiteness Correlation



Model Step Response



Discussion Overview

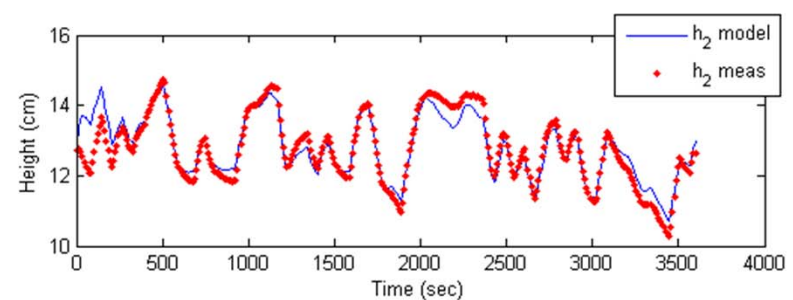
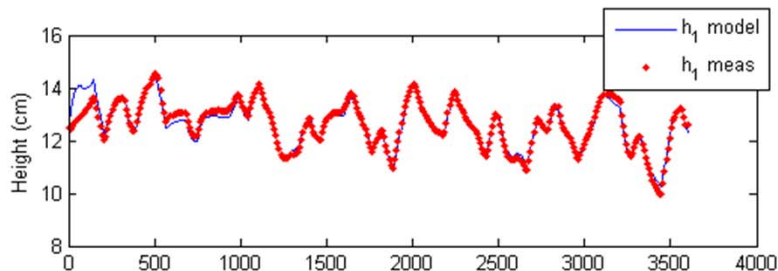
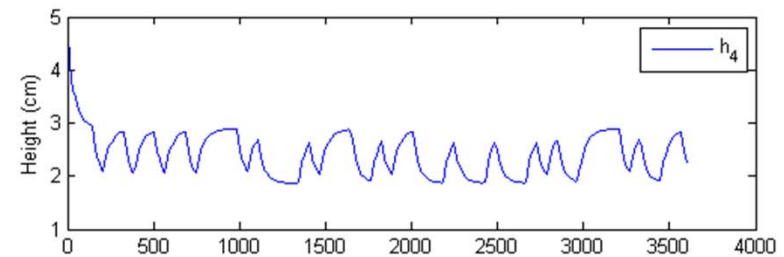
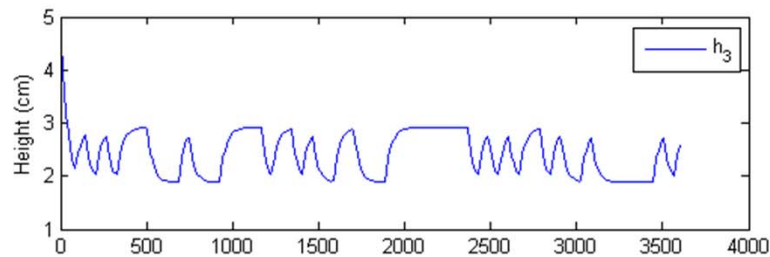
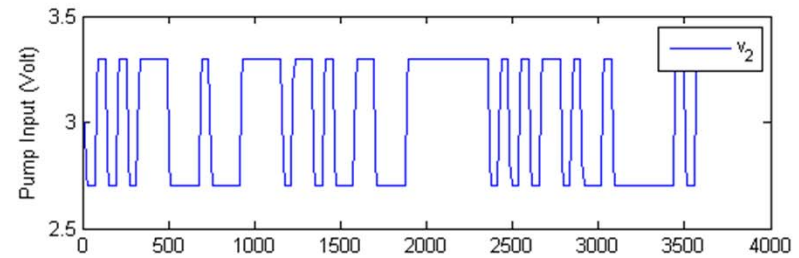
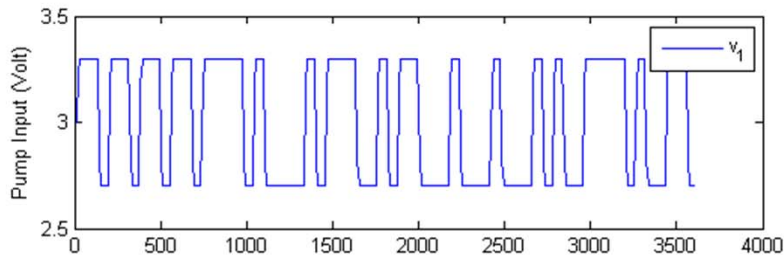


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Nonlinear Parameter Estimation

- First Principles Model (DAE System)
 - Determine valve characterization, split fractions, outlet flow constants (6 parameters) using PRBS generated data



Discussion Overview

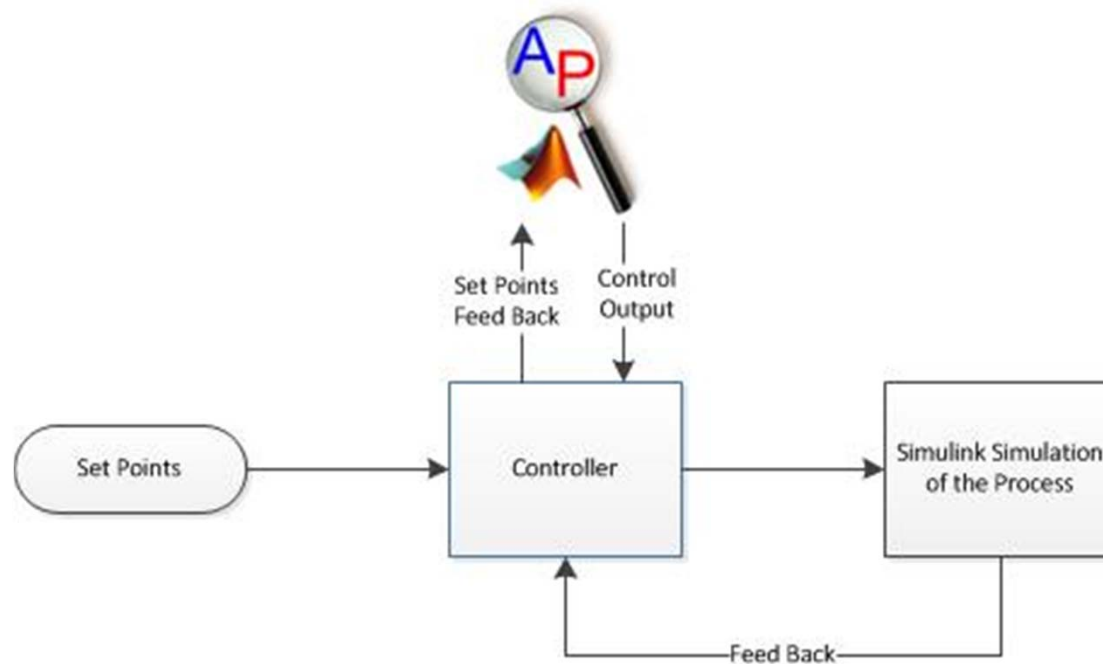


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Nonlinear Control in Simulink

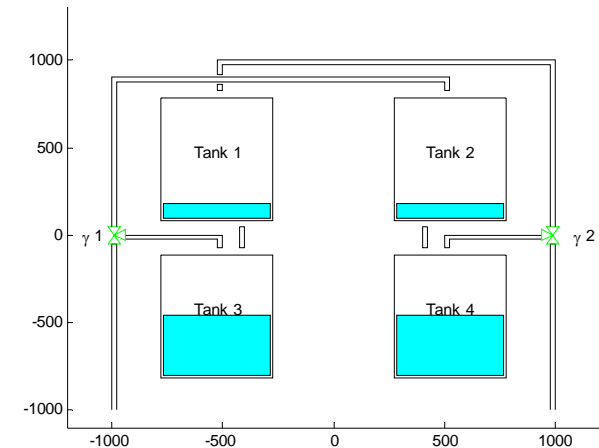
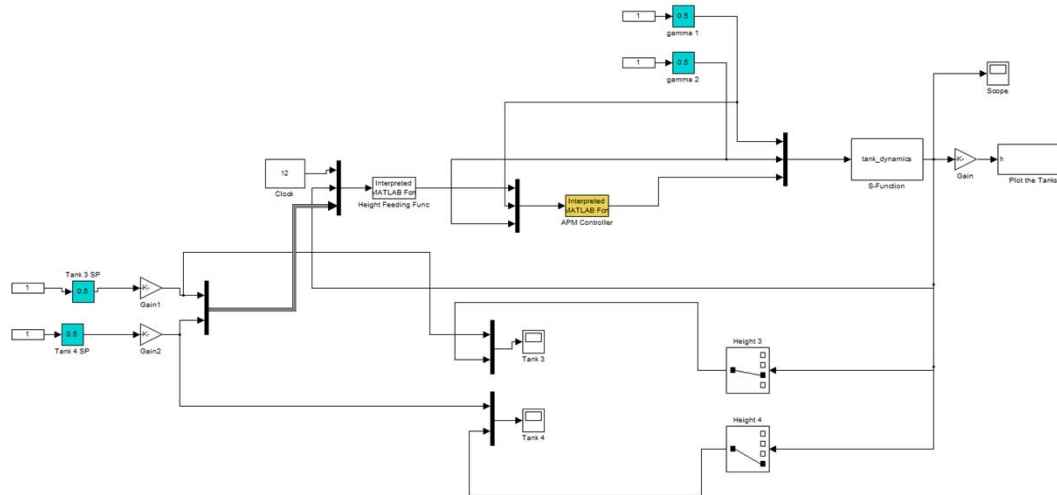
- Implemented APMonitor controller into a Simulink plant simulation
- The controller runs at 5 Hz



Nonlinear Control in Simulink



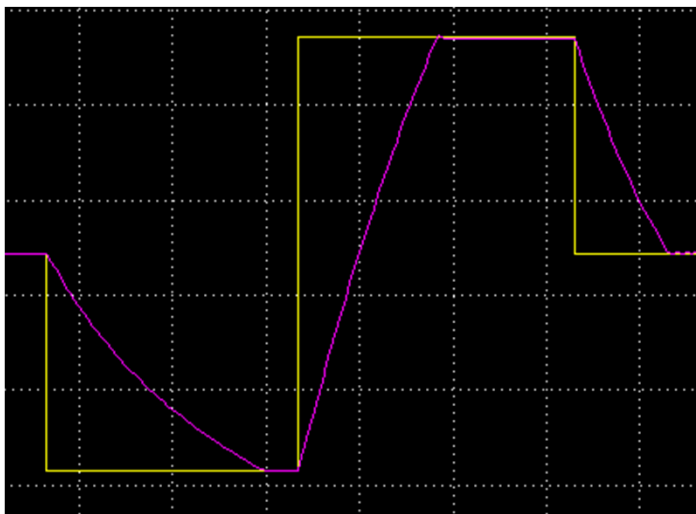
➤ APM Simulink Interface



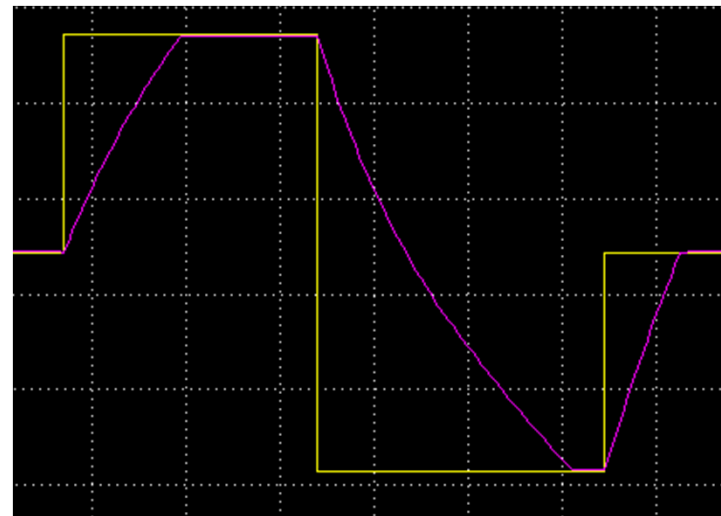
NLC (Nonlinear) Control



- Reverse doublet test results from Simulink simulation:



Tank 1 system response using NLC



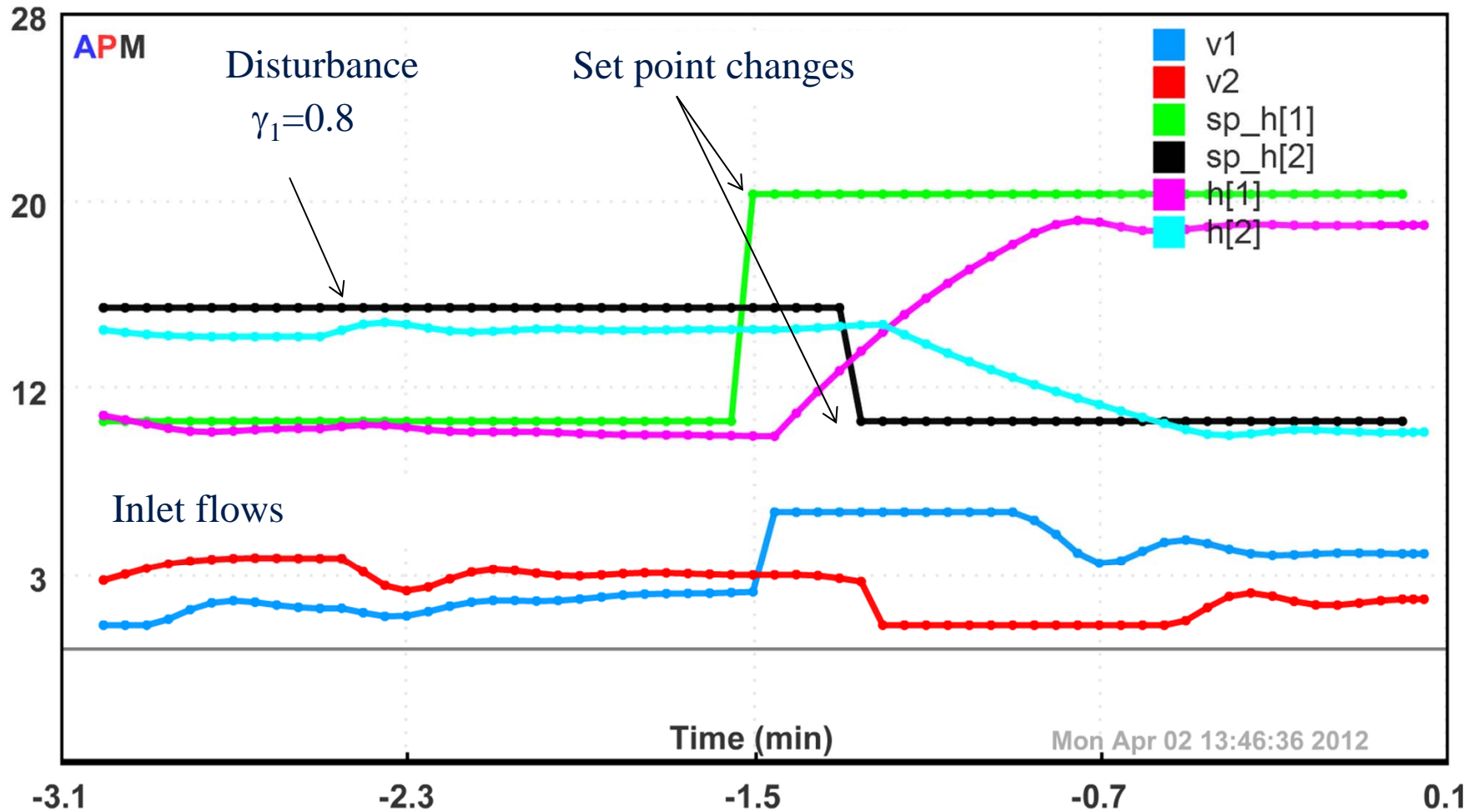
Tank 2 system response using NLC

Discussion Overview

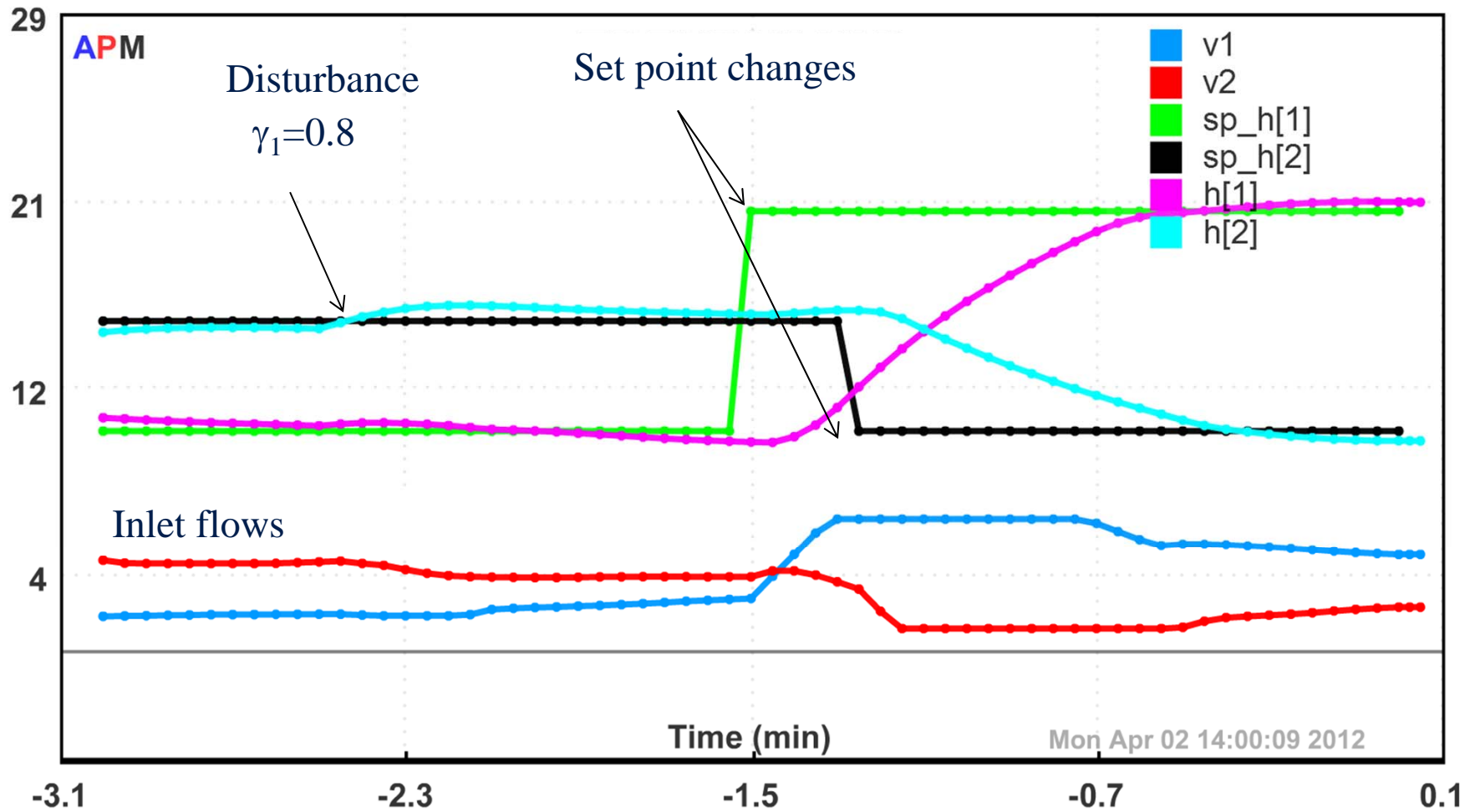


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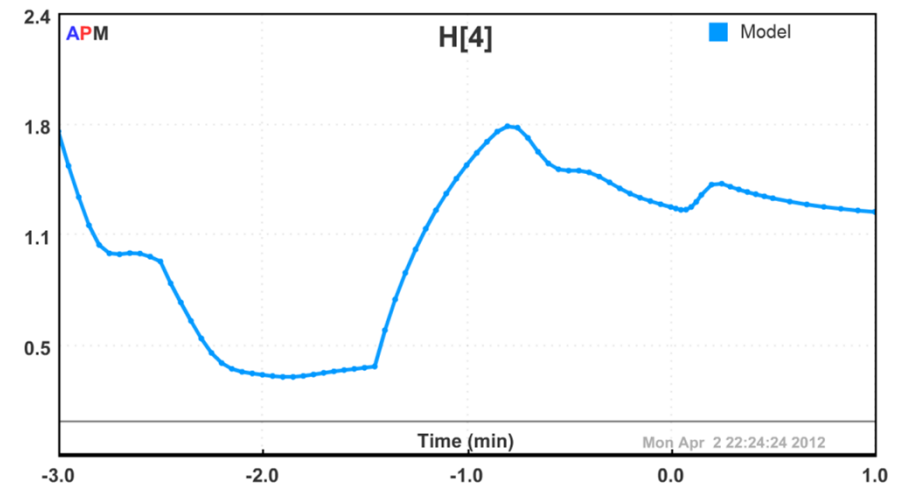
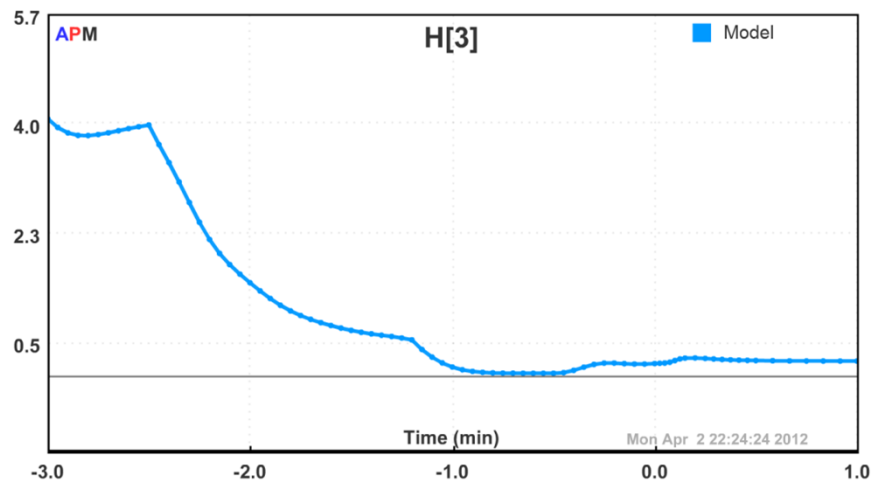
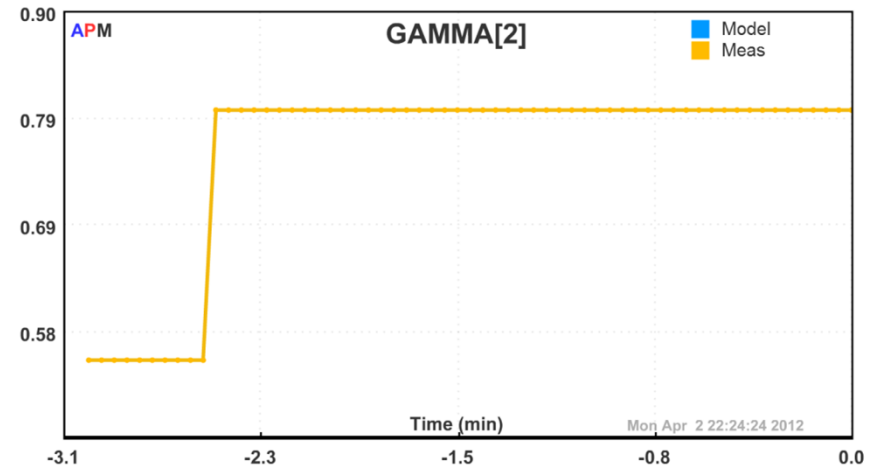
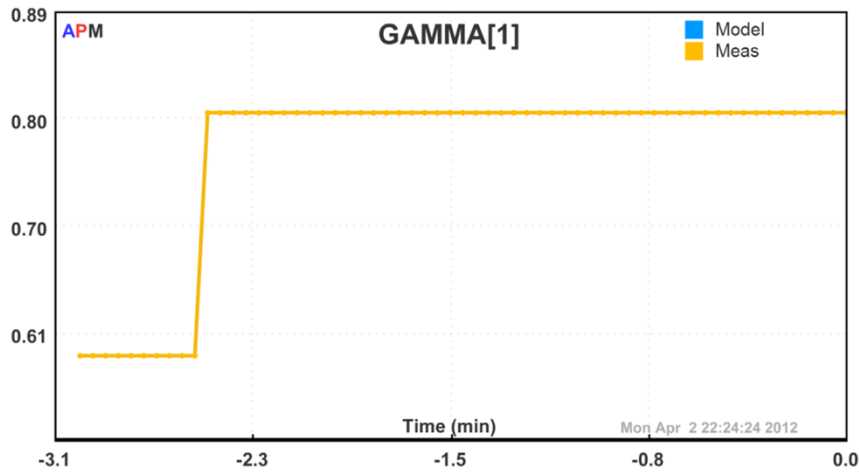
PID Control Performance



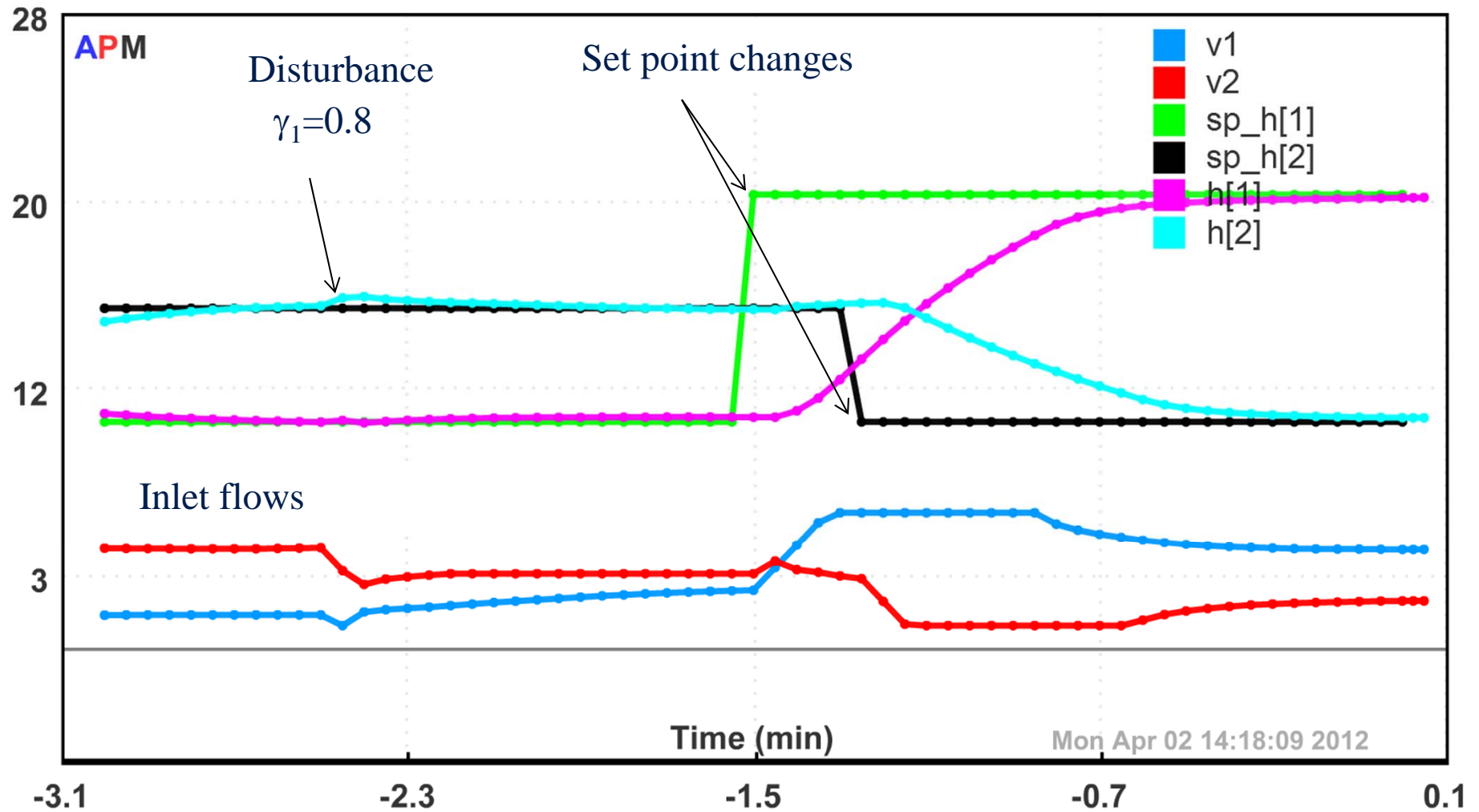
MPC (Linear) Control Performance



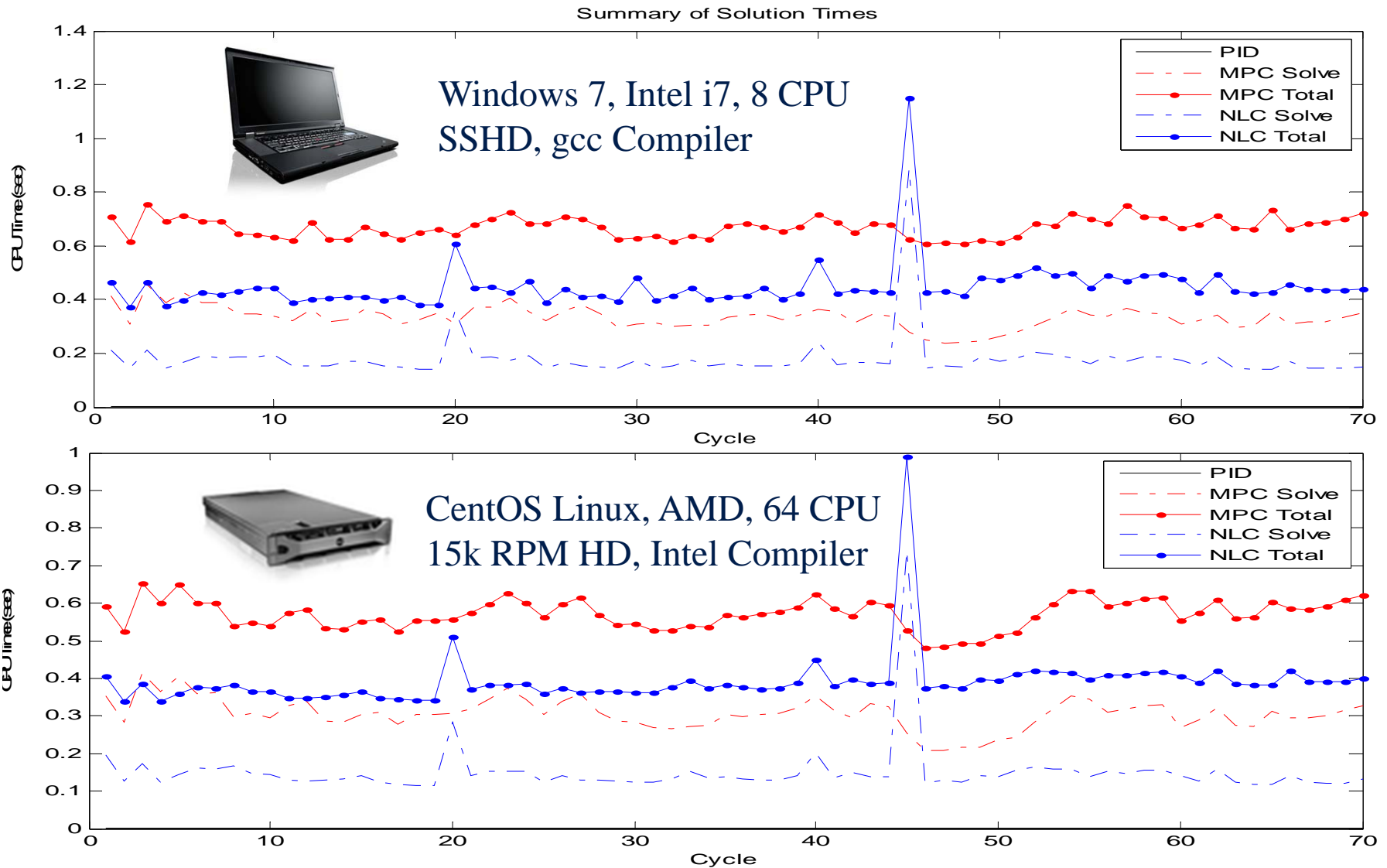
Trends of state variables and disturbances



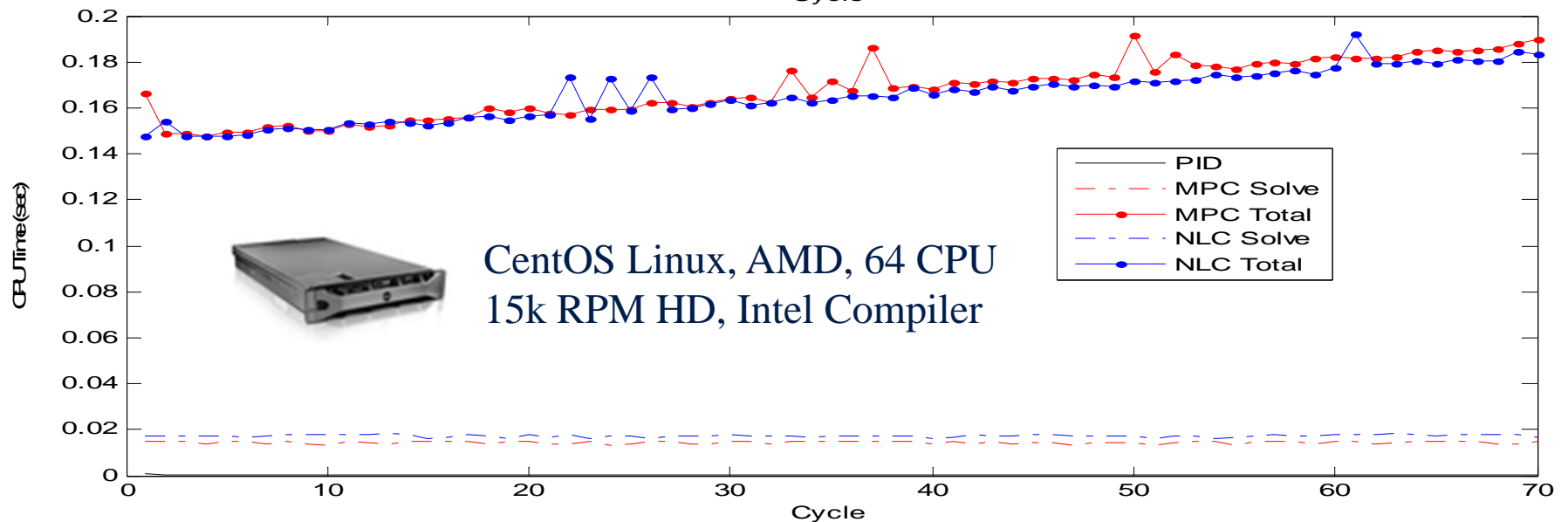
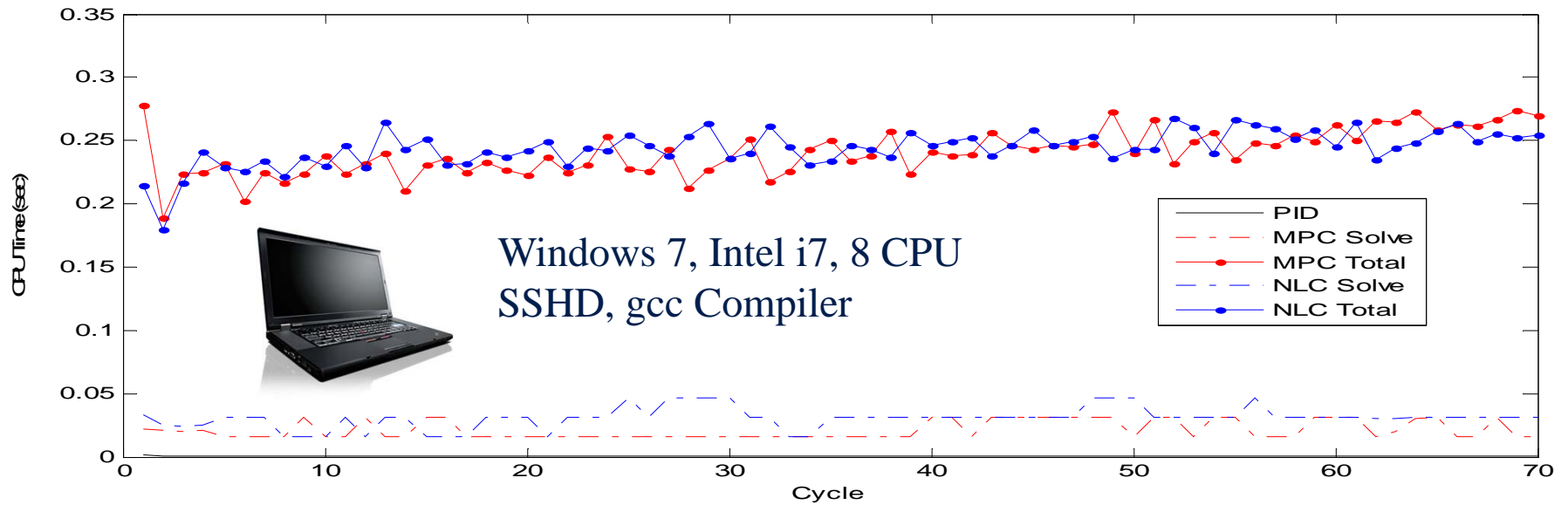
NLC (Nonlinear) Control Performance



CPU Performance – Traditional MPC



CPU Performance – Optimized



Next Generation Control



- Next Generation Modeling and Control Platform?
 - Address usability issues
 - Integrated with Distributed Control System (DCS)
 - Operate efficiently and reliably
 - Use in base control as a replacement for PID control
 - Does storage and retrieval have a place?

- APM Software

APMonitor Modeling Language

The APMonitor Modeling Language is optimization software for differential and algebraic equations. It is coupled with large-scale nonlinear programming solvers for data reconciliation, real-time optimization, dynamic simulation, and nonlinear predictive control. It is available as a free web service or for commercial licensing.



[Try Example Optimization Problems - Demo](#)
Browse or modify example problems to start solving nonlinear programming problems with up to 10 million variables through a web-interface.



[Documentation](#)
APMonitor Documentation Wiki gives details of the modeling language and example applications. [Compare](#) to other popular modeling languages.



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Users share experiences and collaborate through an online discussion forum and regularly scheduled webinars.



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[APM Python Interface](#)
Python gives users an open-source option for solving nonlinear programming problems with a growing community of users.



[APM MATLAB Interface - Demo](#)
MATLAB provides a powerful mathematical scripting language to improve the capability of optimization solutions.