

Improved Load Following of a Boiler with Advanced Process Control

Kevin R. Jensen

Jose Mojica

John D. Hedengren

Brigham Young University

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Energy Future

- ◆ *“Of one thing we can be sure: energy will be more challenging and more important in the future. Will you, and your business, be ready?”*

*--Peter
Schwartz Chairman
Global Business
Network*

- ◆ DOE 25 yr. Energy Forecast
 - ◆ Global demand ↑57%
 - ◆ US Electricity demand ↑40%
- ◆ Effects of Increased Energy Costs
 - ◆ Reduced profits
 - ◆ Decline of sales of energy-intensive products.
 - ◆ Loss of competitiveness



Load Following

- ◆ Why Load Follow?
 - ◆ Accommodate Alt. Energy
 - ◆ Increased Demand
 - ◆ Future Cost is Unsure
 - ◆ Increased Regulation
 - ◆ Climate Change
 - ◆ Ex: Australia
 - ◆ **Peak Energy Costs**

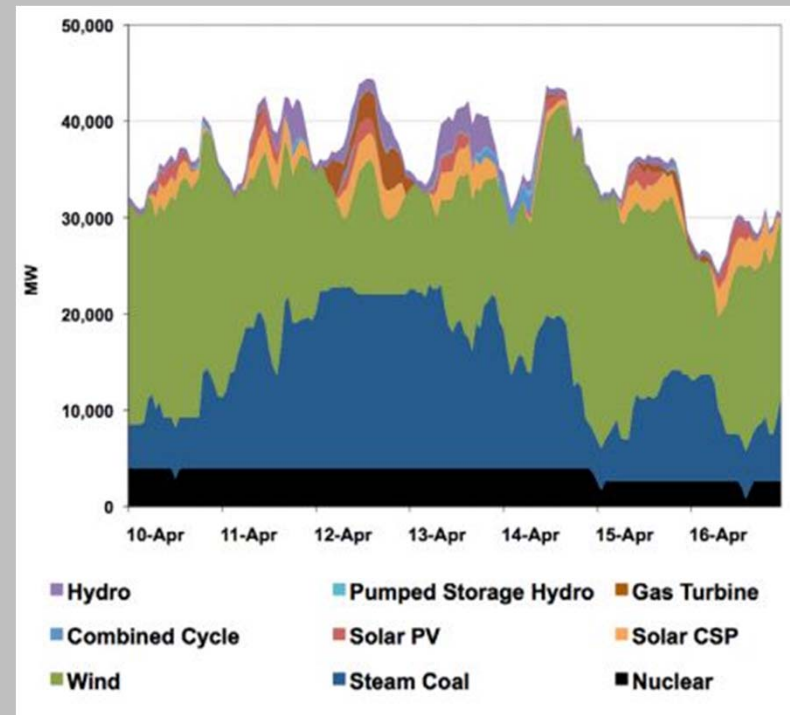


Diagram Courtesy NREL <http://www.nrel.gov/docs/fy11osti/51579.pdf>



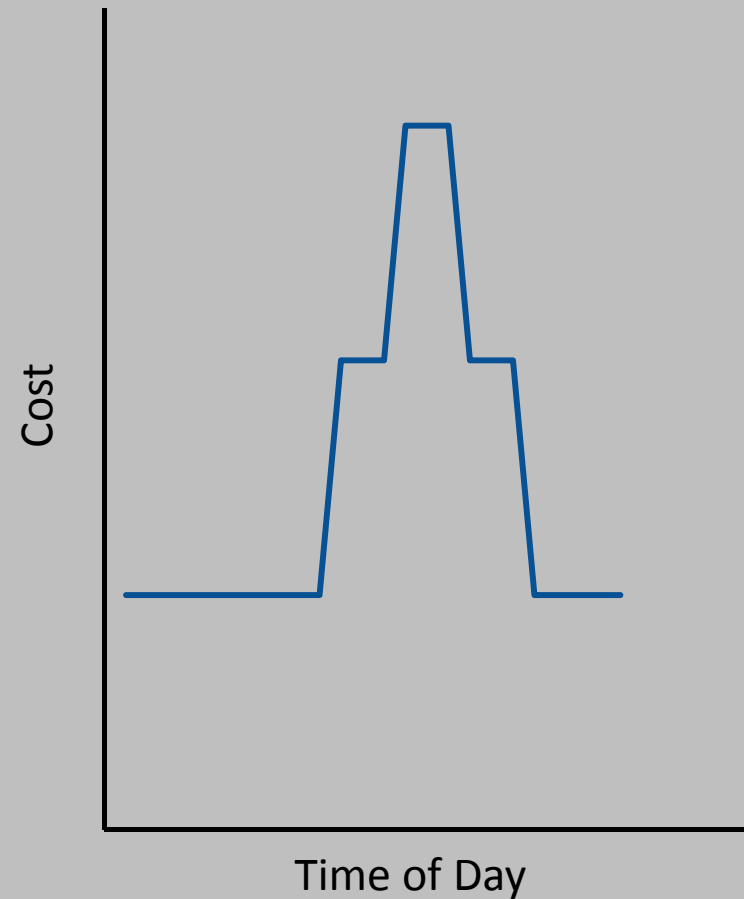
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Peak Time

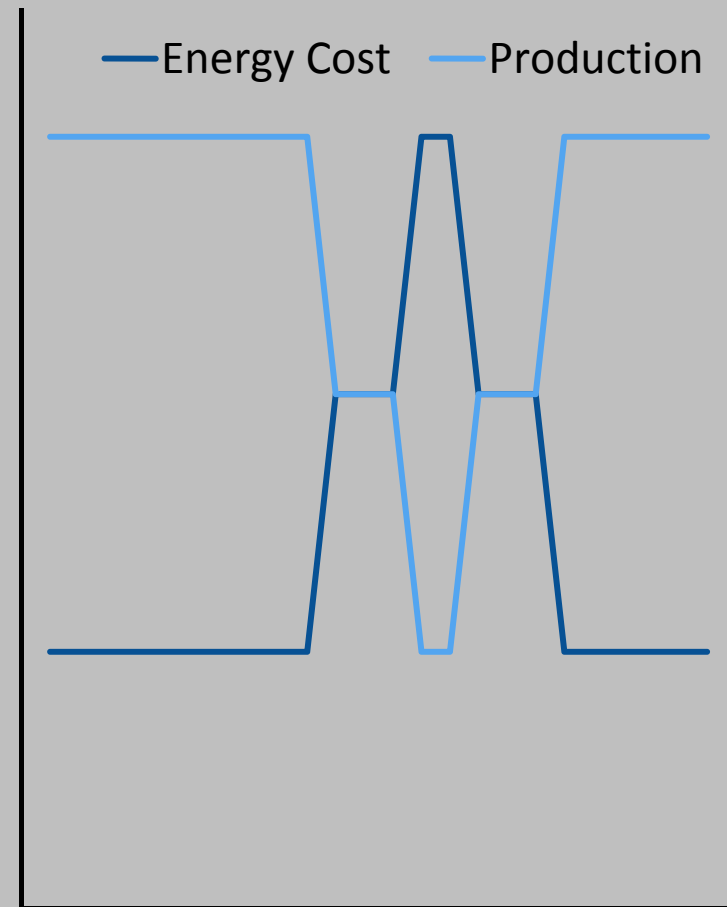
◆ Time of Day Energy Costs

- ◆ Produce own electricity for peak time
- ◆ Peak energy: Up to 2x cost



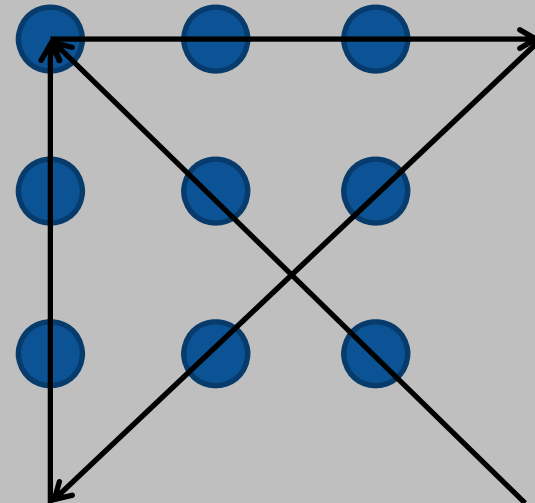
Application for Petrochemicals

- ◆ Compensate cost with production during peak hours
 - ◆ Increase for non-peak hours
 - ◆ Decrease for peak hours
 - ◆ Make money by decrease production?
 - ◆ Possibly decrease capital cost



Control System Developments

- ◆ Typically based on:
 - ◆ Operator Knowledge
 - ◆ Safe
 - ◆ Meet Requirements
 - ◆ Successful
 - ◆ Perceived Limitations
 - ◆ Challenge assumptions
 - ◆ Optimize everything



Special Controls

- ◆ Most processes have unique operating conditions and requirements
- ◆ Ex: Boiler for steam/energy production
 - ◆ Load change at specified rate
 - ◆ Wear and tear
 - ◆ Emissions



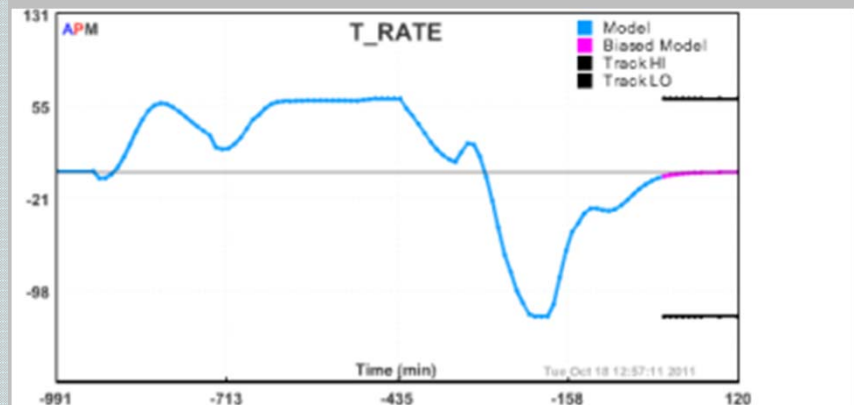
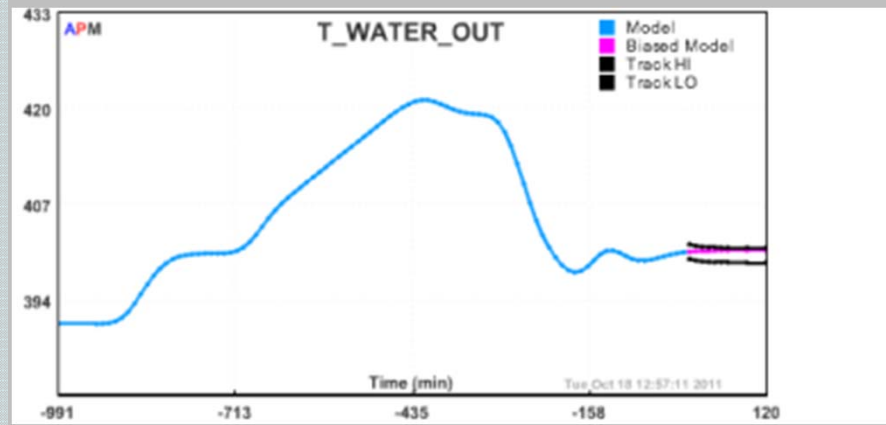
Model

- ◆ Model Source
 - ◆ Operational knowledge from
 - ◆ Literature values
 - ◆ Heat transfer equations
 - ◆ Material and energy balances
- ◆ Model Form
 - ◆ Differential and Algebraic Equations (DAEs)
 - ◆ Combined Empirical and First Principles forms



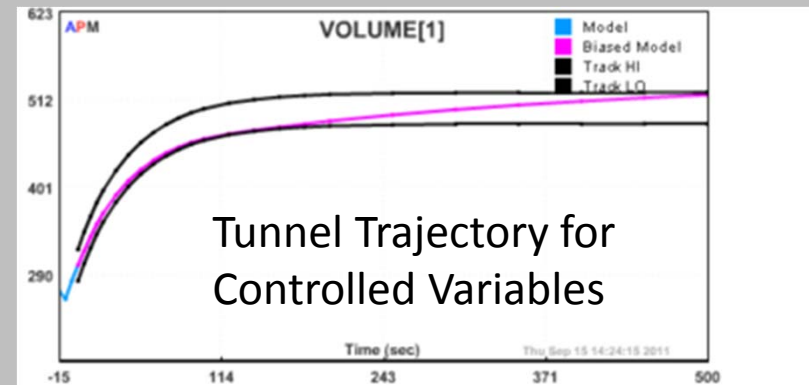
Nonlinear Model Predictive Control

- ◆ Trajectory tracking
- ◆ Other constraints can be specified
 - ◆ Rate of Temperature Change
 - ◆ Emissions, Costs, Process unit life, etc.



Nonlinear Model Predictive Control

- ◆ Effective over entire range of interest
 - ◆ Load Following
 - ◆ Large Disturbances
 - ◆ Steady State
 - ◆ Transient
- ◆ Large-scale problems
 - ◆ Sparse NLP solvers
 - ◆ Simultaneous Solution Approach



$$\min_u J(x, u, \Delta u)$$

$$s.t. \dot{0} = f(\dot{x}, x, u)$$

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

$$0 < h(x, u)$$

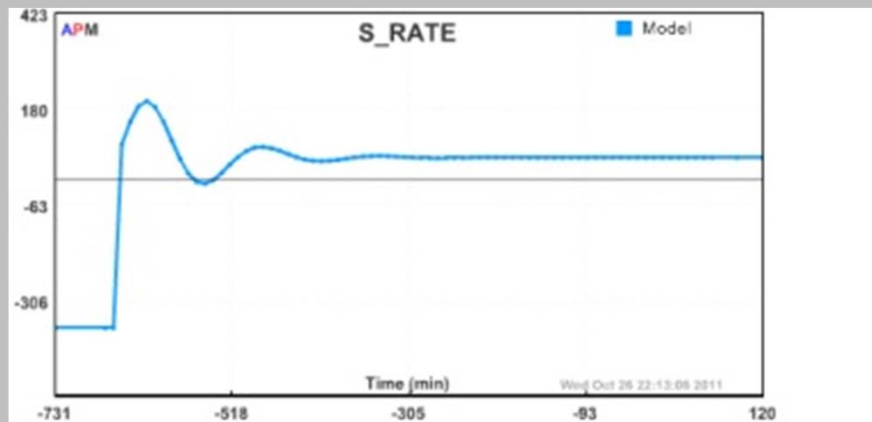
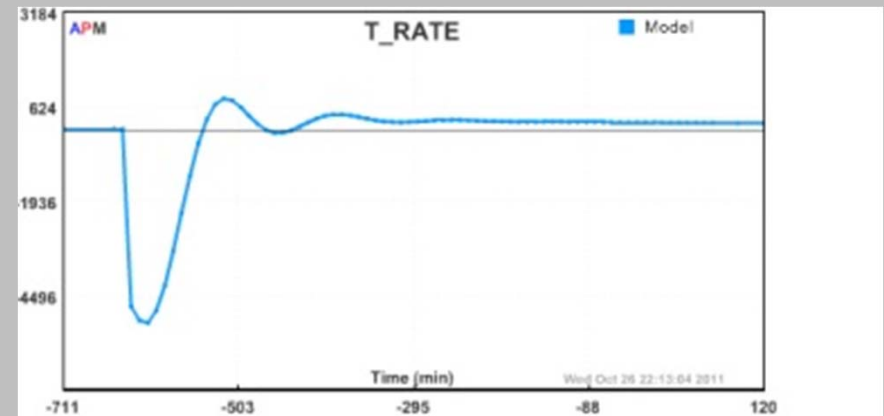
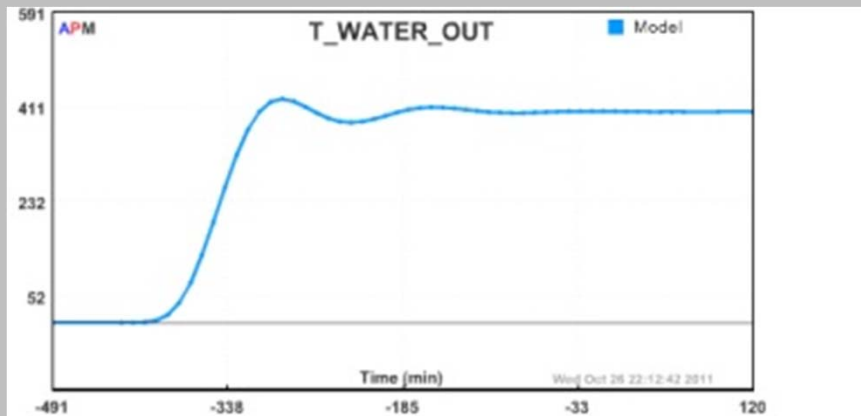


PID Controller

- ◆ SIMPLE
 - ◆ Easy to Use
- ◆ Effective for:
 - ◆ Steady state
 - ◆ Small Disturbances
- ◆ Ineffective
 - ◆ Load Cycling
 - ◆ Frequently Saturated
 - ◆ Violated Rate Constraints



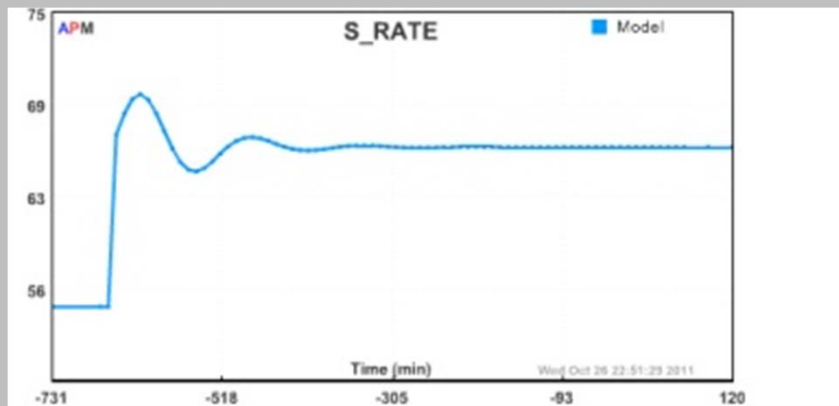
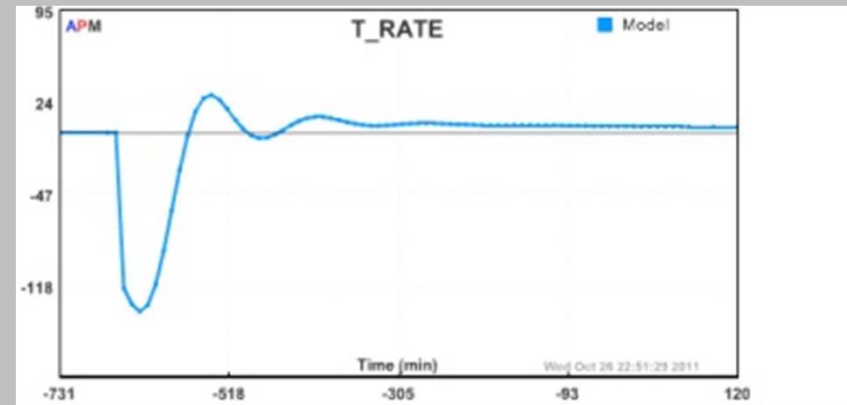
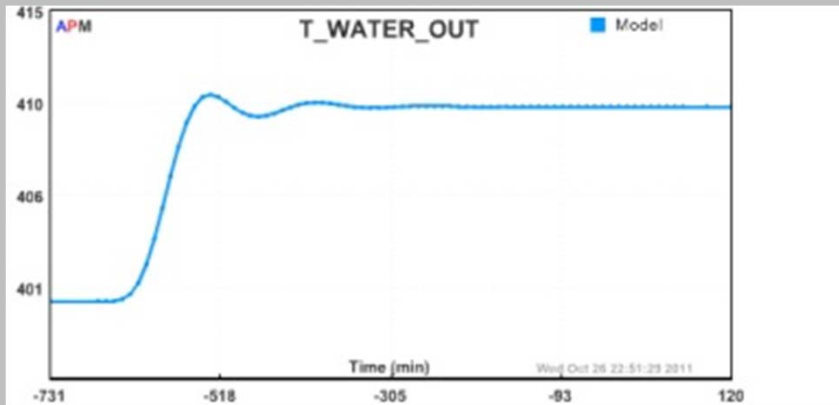
PID Start-Up



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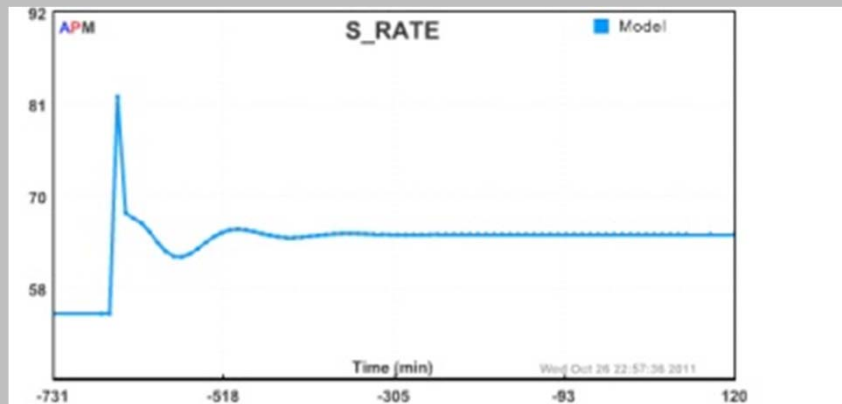
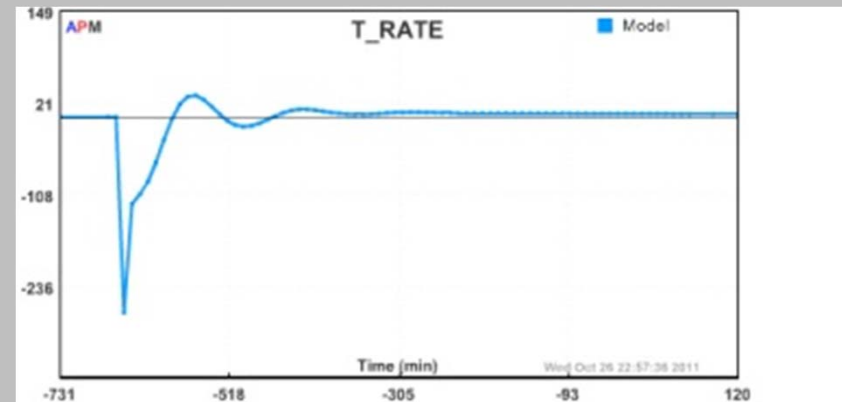
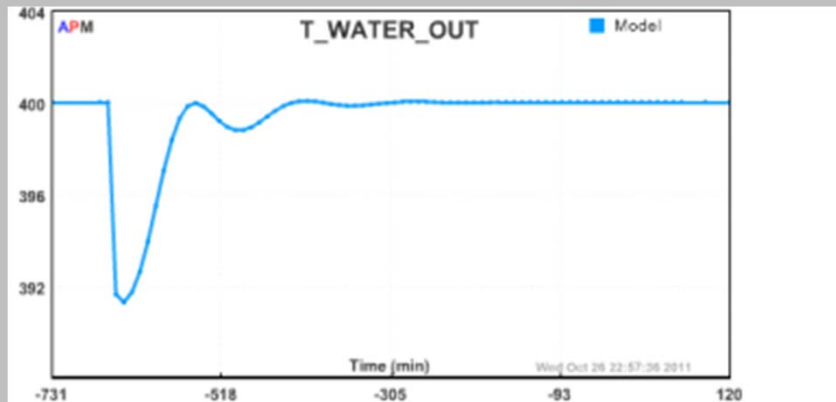
PID Set Point Change



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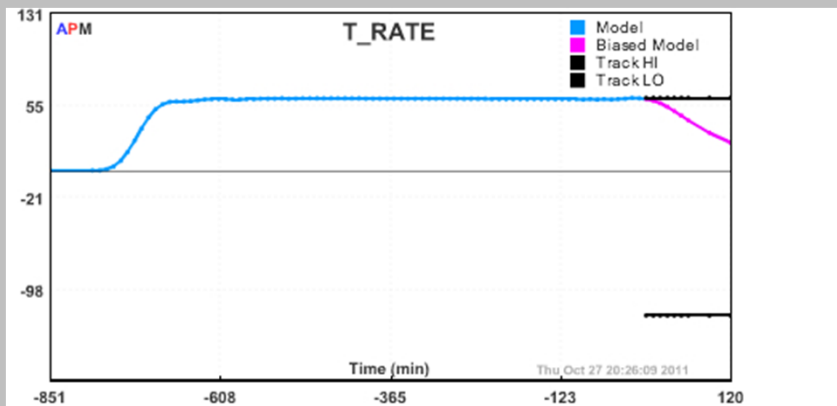
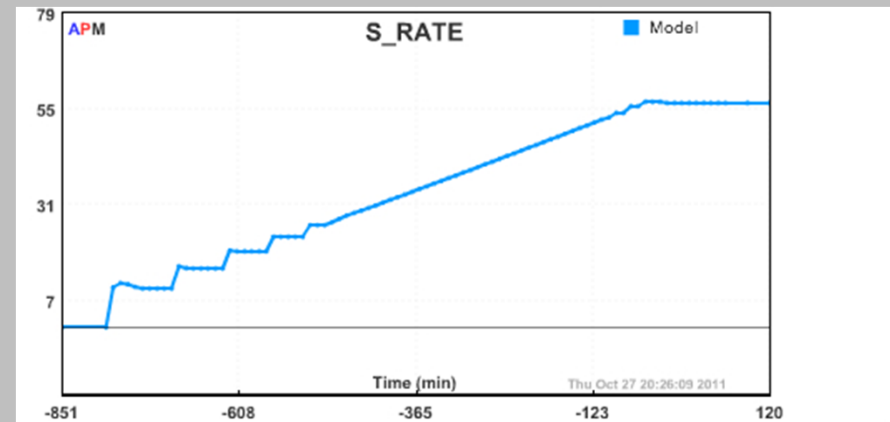
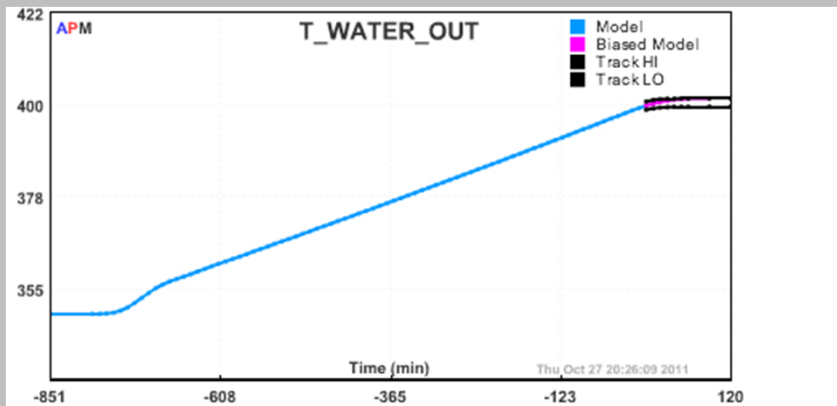
PID Disturbance



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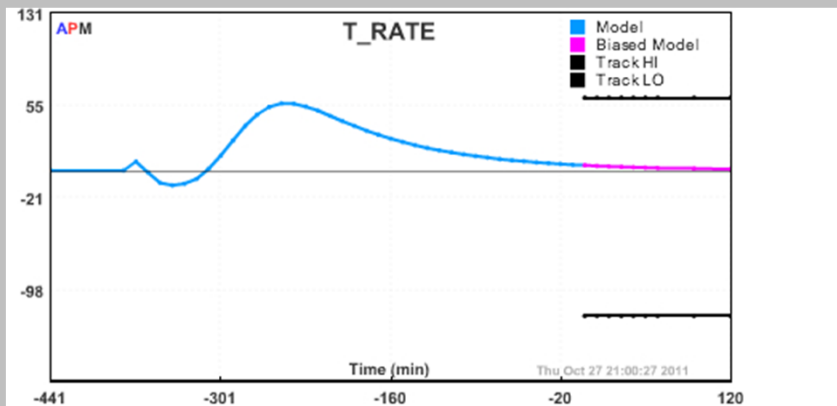
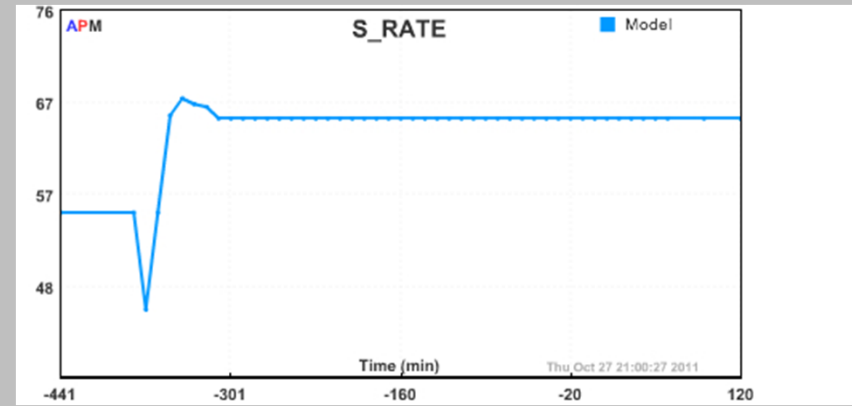
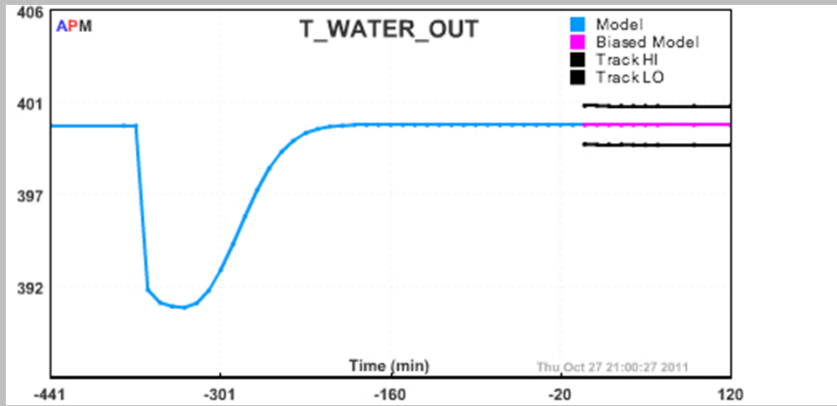
NLC Start Up



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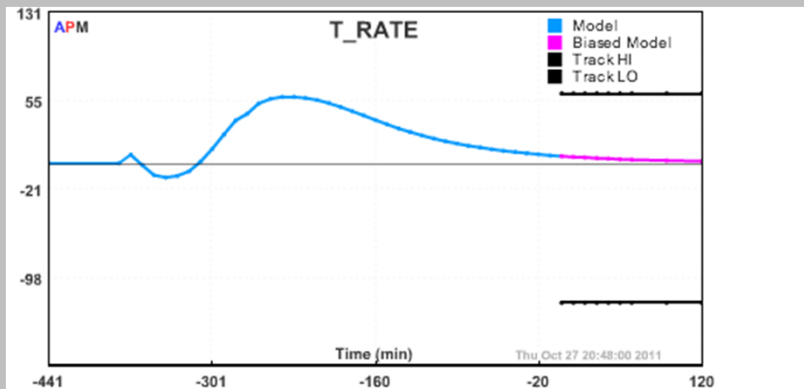
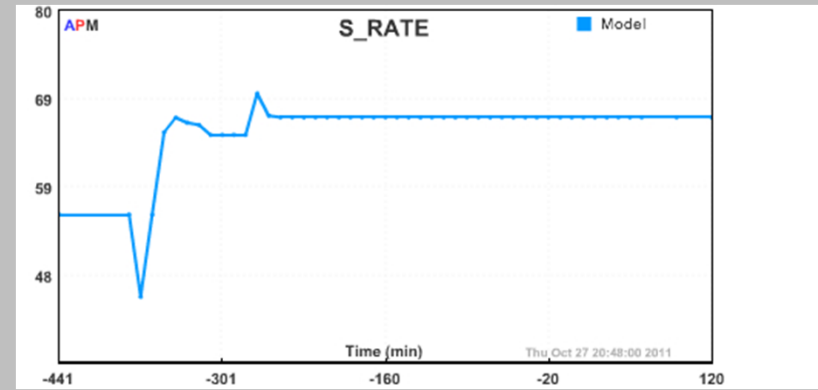
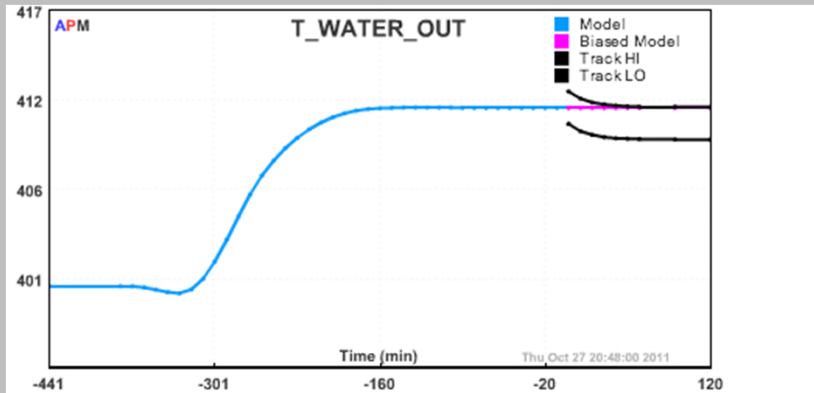
NLC Disturbance



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NLC Set Point Change

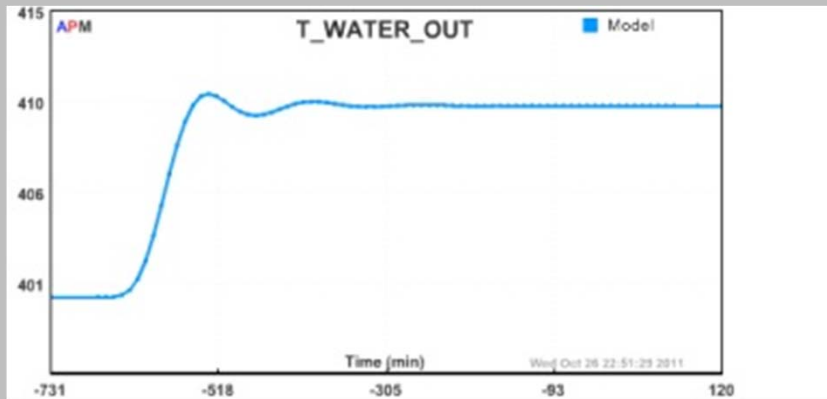


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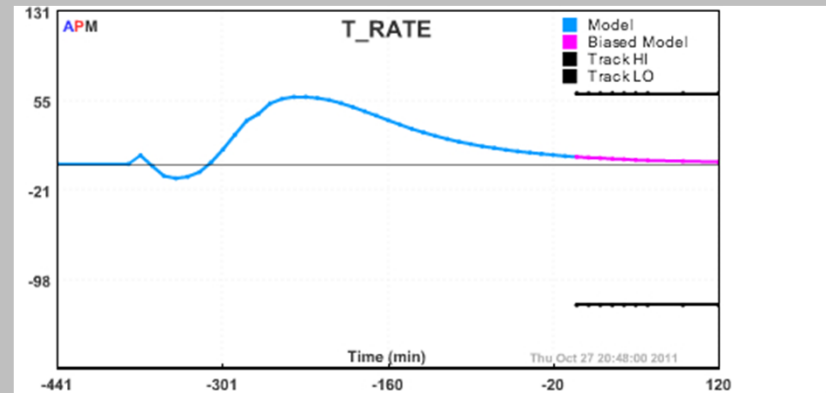
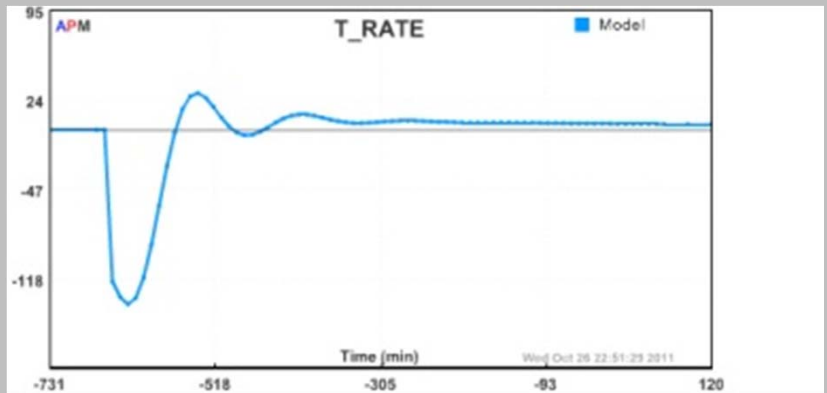
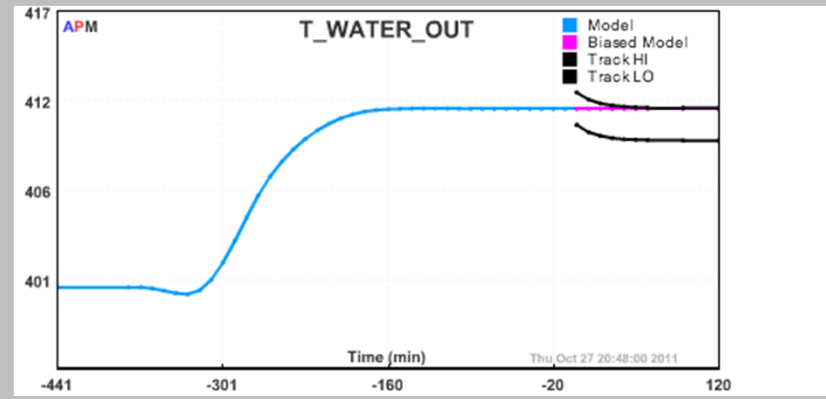
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Comparison of Set Point Changes

PID Control



Nonlinear Control



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Model-Based Controller

- ◆ Challenges restrictions by driving to actual process constraints
 - ◆ Optimized load changes
 - ◆ i.e. Faster/slower, boiler life
- ◆ Explicitly Targeted Constraints



Future Work

- ◆ Forecasting:
 - ◆ Energy availability
 - ◆ Time of day pricing
 - ◆ Peak power demands
- ◆ Energy storage
 - ◆ Optimize design and operation
 - ◆ Meet peak demand with lower base-load

