MODEL PREDICTIVE CONTROL OF COMPRESSOR NETWORKS

Master's Thesis: *Midterm* Presentation

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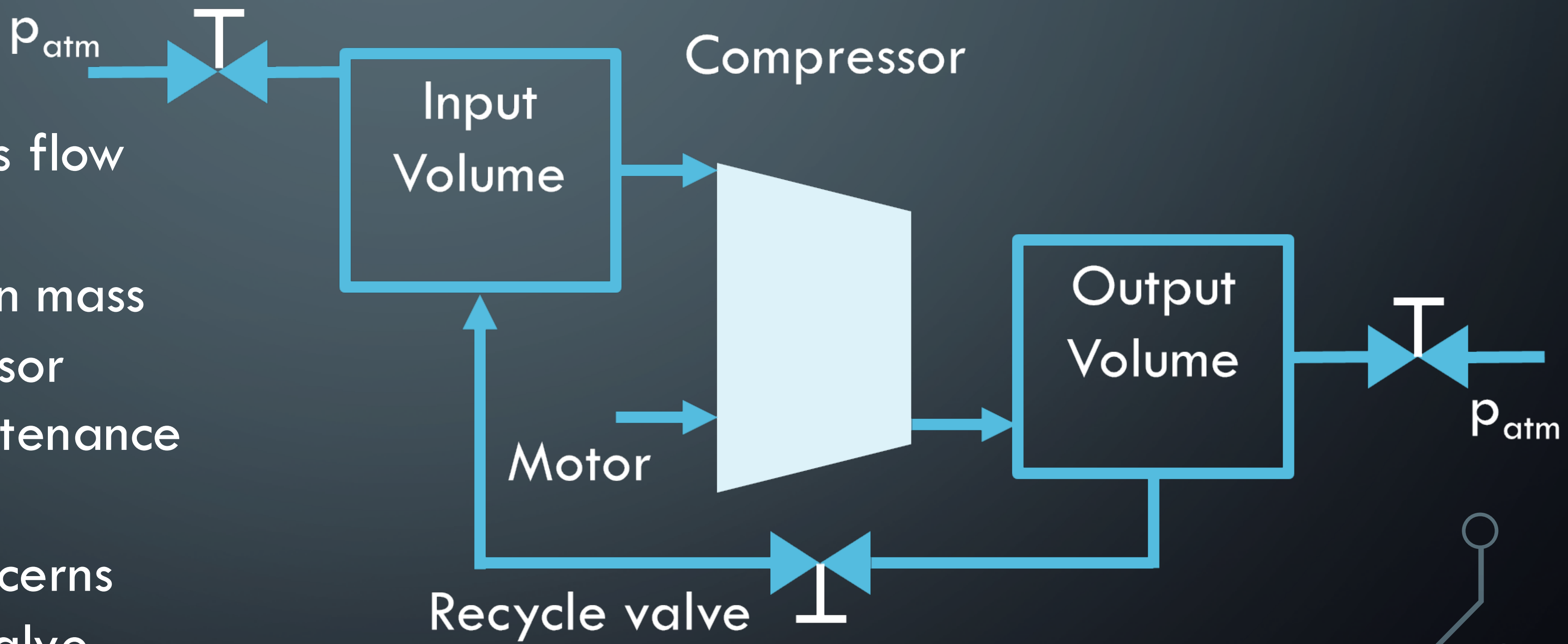
Introduction

System: Compressor Surge

- Causes:
  - Increased pressure ratio/decreased mass flow
- Effects:
  - Unstable oscillations in mass flow through compressor
  - Increased wear/maintenance cost
  - Can cause safety concerns
- Avoidance with recycle valve



Introduction

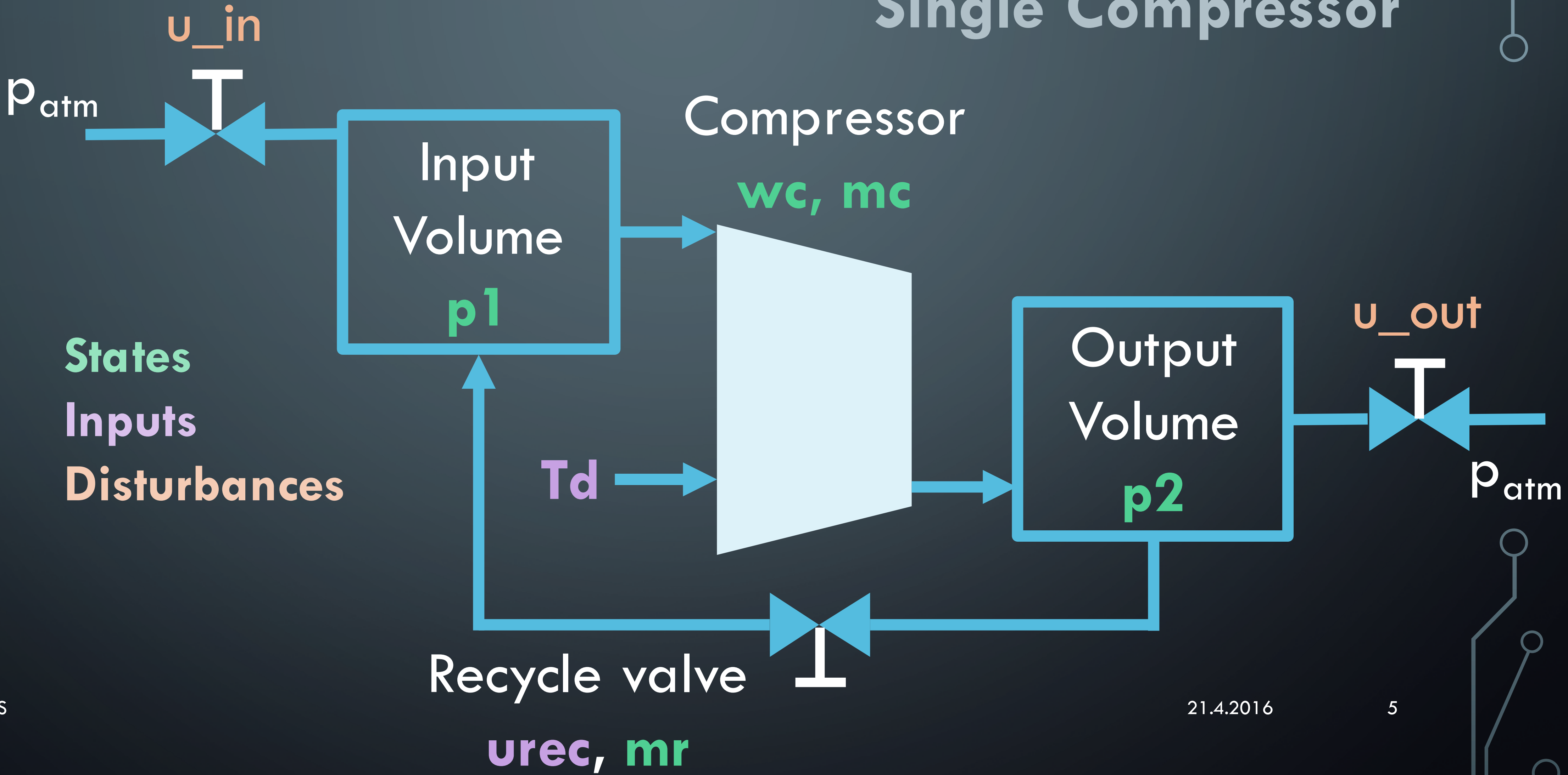
Current Industry Practices

- Dedicated surge avoidance controller:
  - Feedback loop for small disturbances
  - Additional feedforward terms when certain thresholds are crossed
  - Loop decoupling to separate it from pressure control/for multiple compressors
- Disadvantages:
  - Designed for gas turbines – don’t take advantage of quick response of electric drivers
  - No explicit consideration of input constraints
  - Interaction of multiple controllers

Introduction
Thesis Goals

- Design and simulate MPC controllers for both parallel and serial networks of two compressors
  - Needs to be computationally efficient
  - Implemented by each compressor independently
- Why MPC?
  - Already been shown that MPC increases surge avoidance performance relative to traditional controllers for single compressors
  - Can naturally handle interactions & input constraints

Modelling
Single Compressor

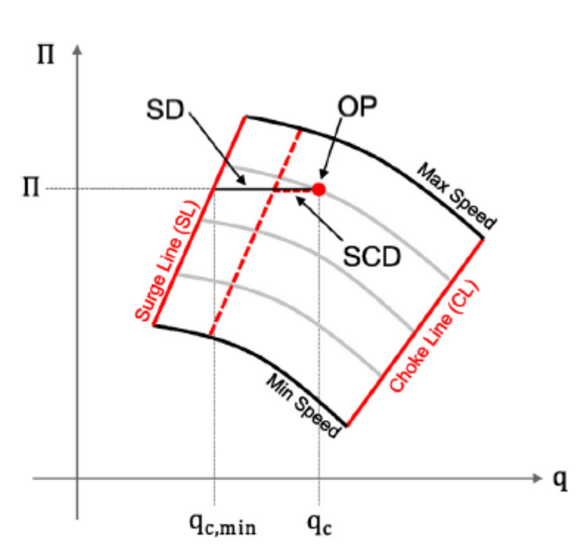


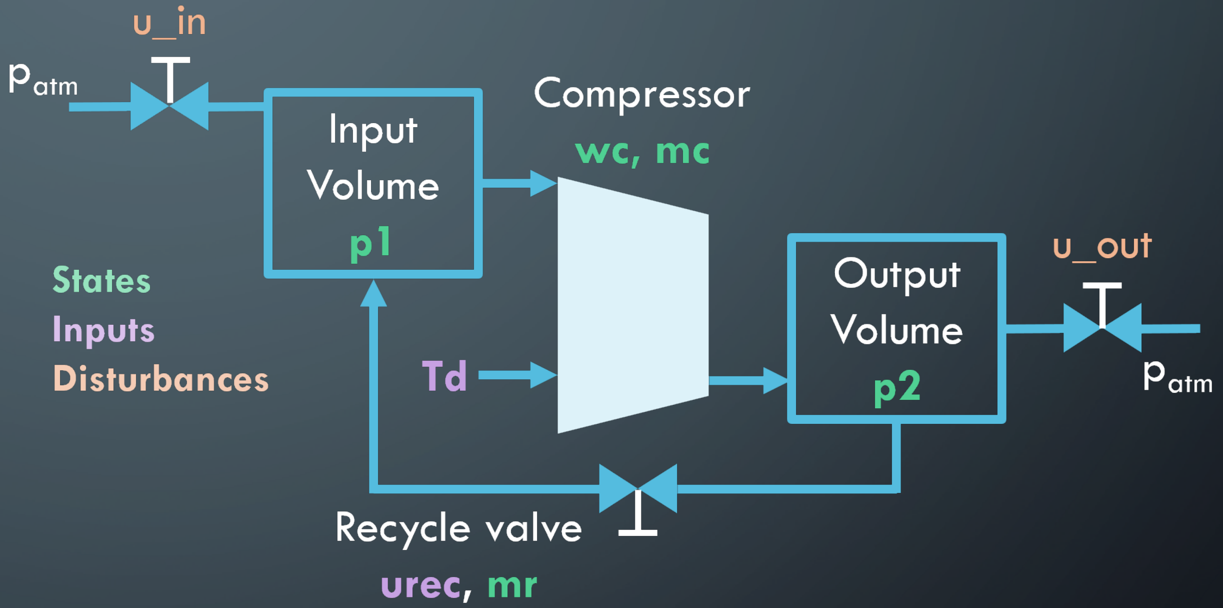
States
Inputs
Disturbances

Modelling
Single Compressor

Outputs

- p2: Output pressure
- SD: Surge distance





$$SD = -c_1 \frac{p_2}{p_1} + c_0 + m_c$$

Modelling
Approach

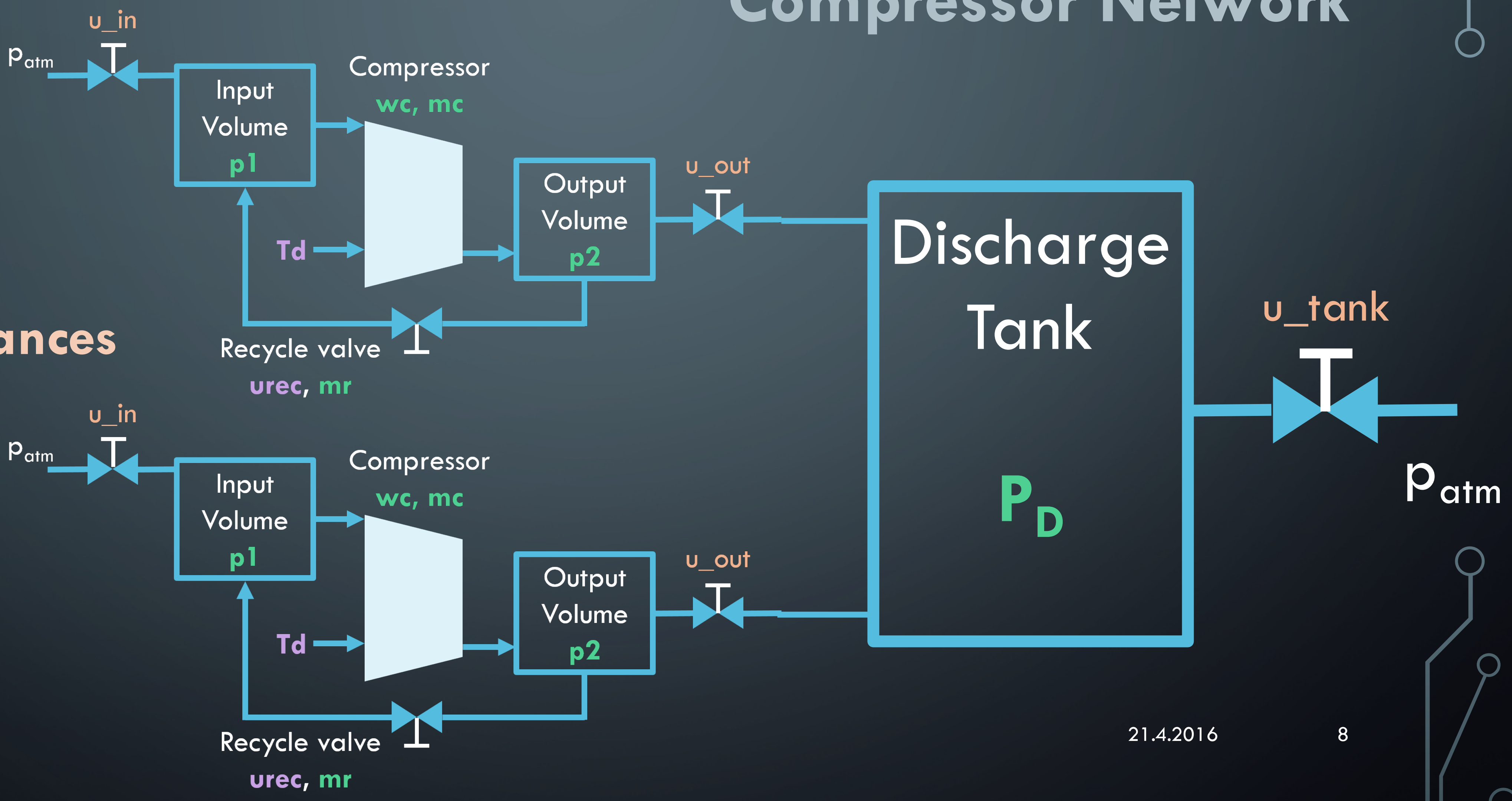
- Grey-box modelling:
  - Combination of parameter fitting and first principles
  - Fix order of model based on first principles
  - Use steady-state measurements to determine static model parameters
  - Dynamic parameters taken equal to physical characteristics

Modelling
Compressor Network

States

Inputs

Disturbances



Control
Overview

- Linearized MPC
- Prediction horizon: p = 100
- Move horizon: u = 2
- Augmented state includes:
  - 5 states per compressor
  - Discharge tank pressure
  - 20-40 recycle valve delay states
  - 2 integrator states/compressor

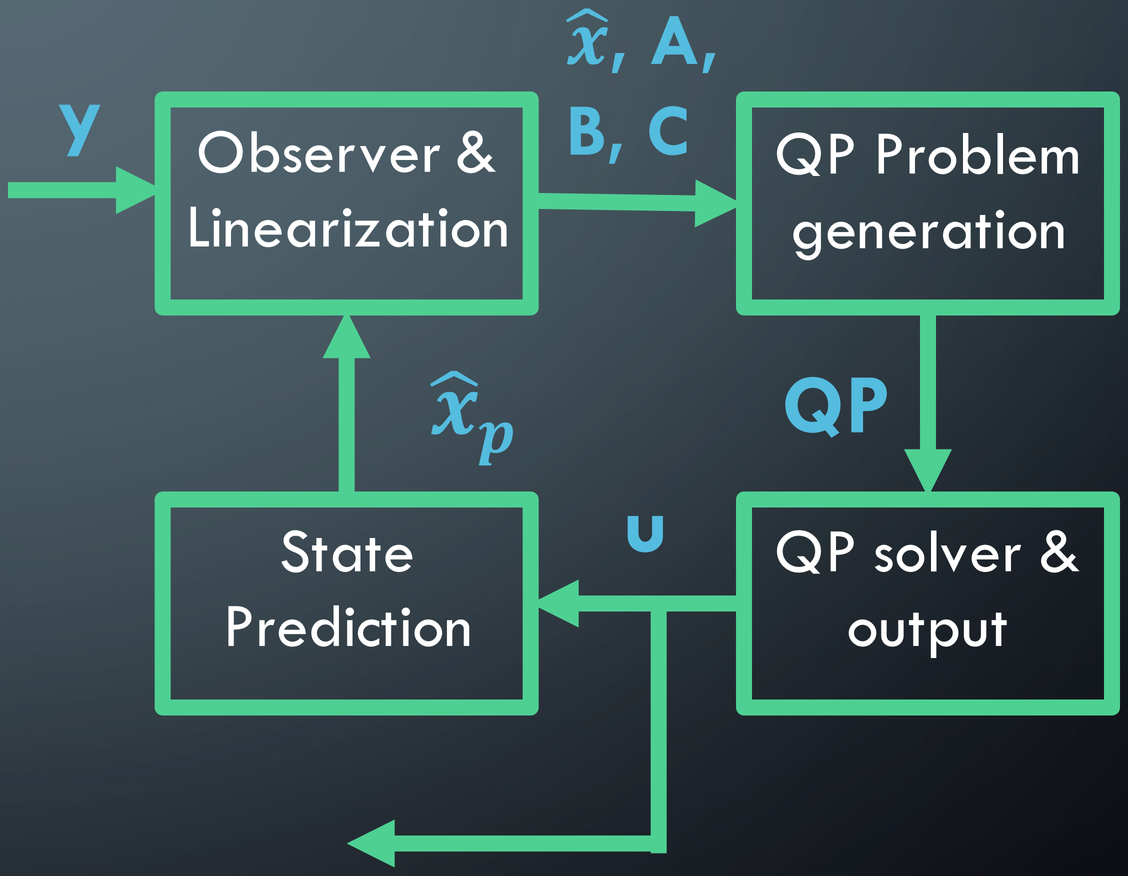
- Primary control objective: **surge control** of both compressors
- Secondary control objectives:
  - follow discharge pressure setpoint
  - keep both output pressures equal (or objective from load-sharing controller)

Control

Controller Setup

Procedure at each time step:

1. A posteriori state estimation
2. Linearize/discretize system around current operating point
3. Set up & solve QP
4. Apply optimal inputs
5. A priori state prediction



Control
Equations

Objective: $$\min_{\Delta Y, \Delta u} (\Delta Y - \Delta Y_{REF})^T \; W_y \, (\Delta Y - \Delta Y_{REF}) + \; \Delta u^T \, W_u \, \Delta u$$

Such that: $$\Delta Y \; = S_x \Delta x + \; S_u \Delta u + S_{\dot{x}} \dot{x}(x_0)$$

$$\Delta u_{min} \leq \Delta u \; \leq \; \Delta u_{max}$$

where Δ is relative to the linearization point

Control
Centralized Approach

- 4 inputs, 4 outputs
- Likely too computationally expensive to implement in practice
- Used as benchmark for other controllers
- Outputs: SD and p2 for both compressors

Control

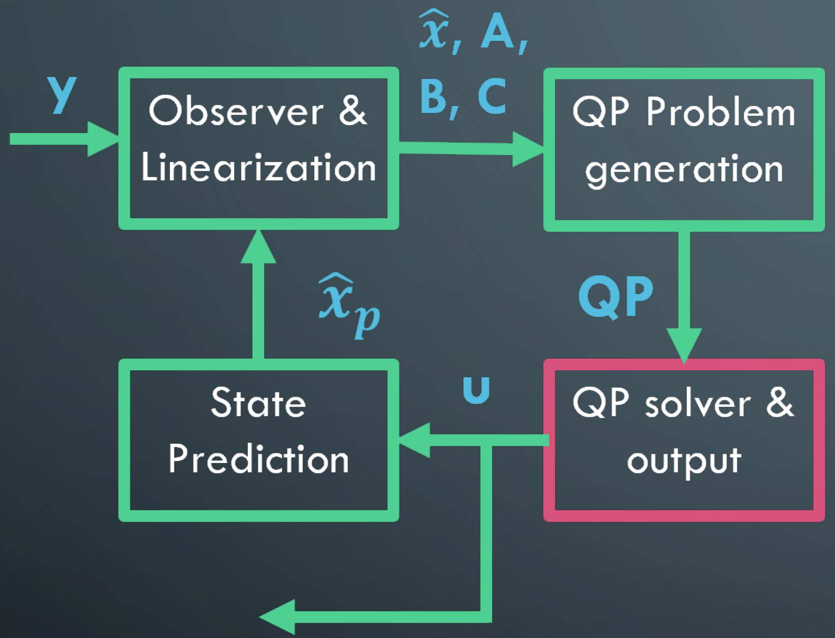
Decentralized Approach

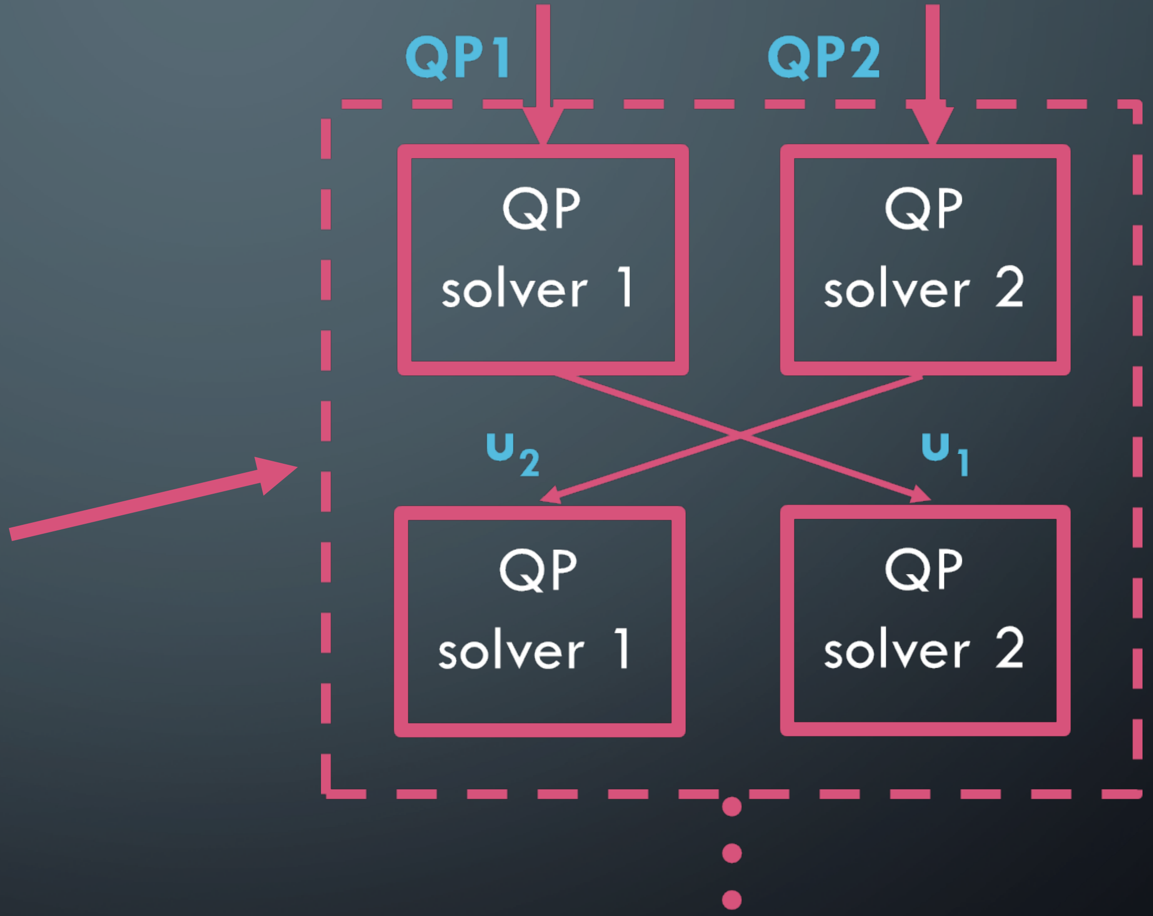
$$\Delta Y = S_x \Delta x + S_{u1} \Delta u_1 + S_{u2} \Delta u_2 + S_{\dot{x}} \dot{x}(x_0)$$

- Solve separate, smaller QP for each controller individually
  - Each QP depends on inputs of other compressor – unknown
  - Perform fixed # of iterations, updating the inputs at each step
- Assume full state information available to both compressors (for now)
  - Can also implement separate observers for each compressor
- 2 variants examined
  - Cooperative: use single cost function for both compressors
  - Non-cooperative: use separate cost function for each compressor

Control

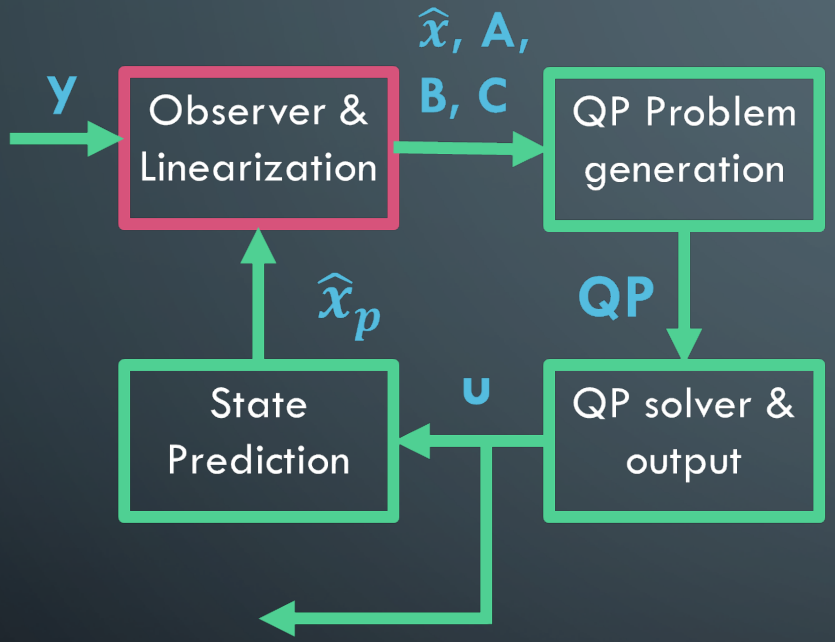
Decentralized: QP Solver

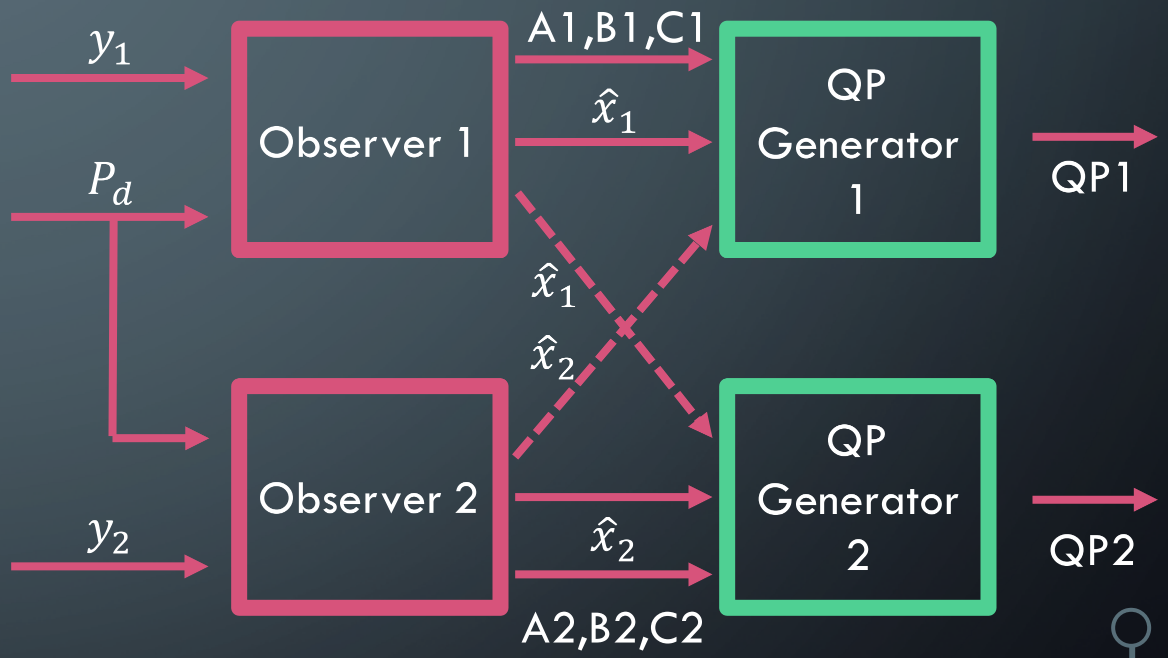




Control

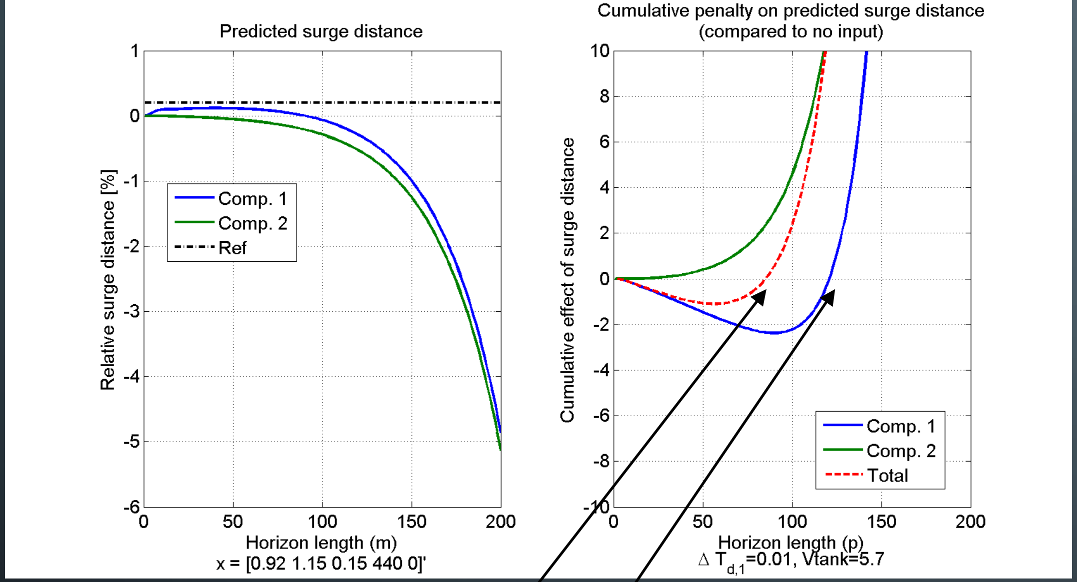
Decentralized: Observer

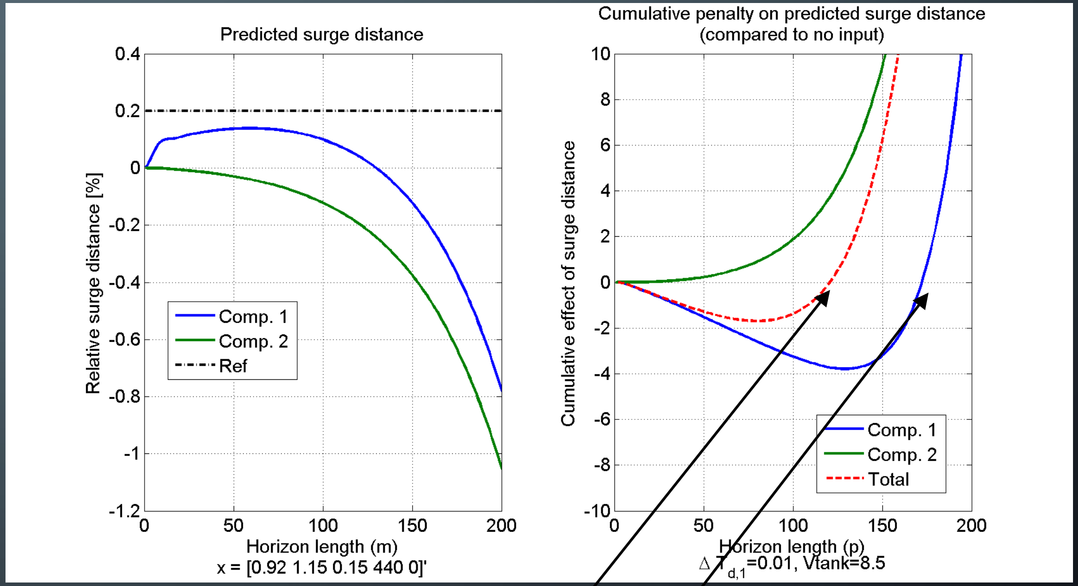




Considerations
Tank Size

Assume steady-state and use prediction matrices to predict QP solution:



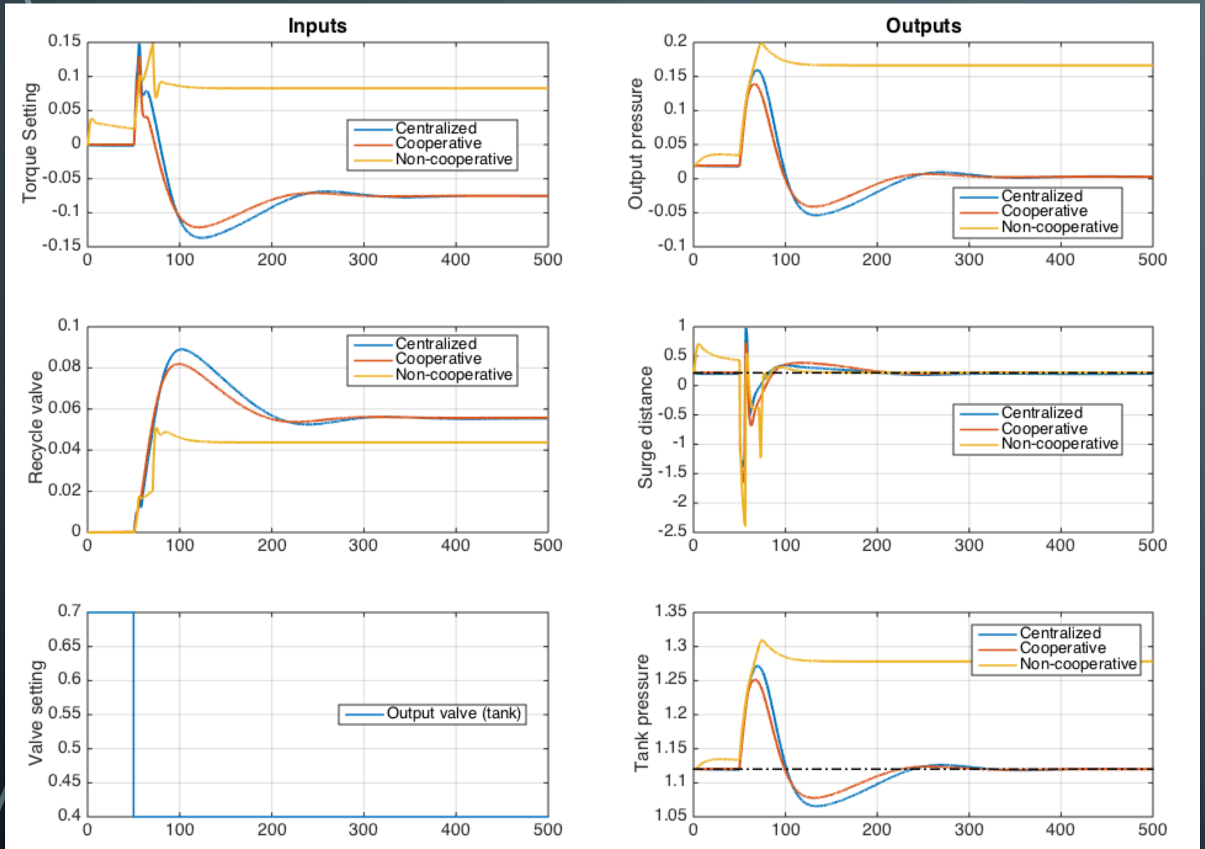


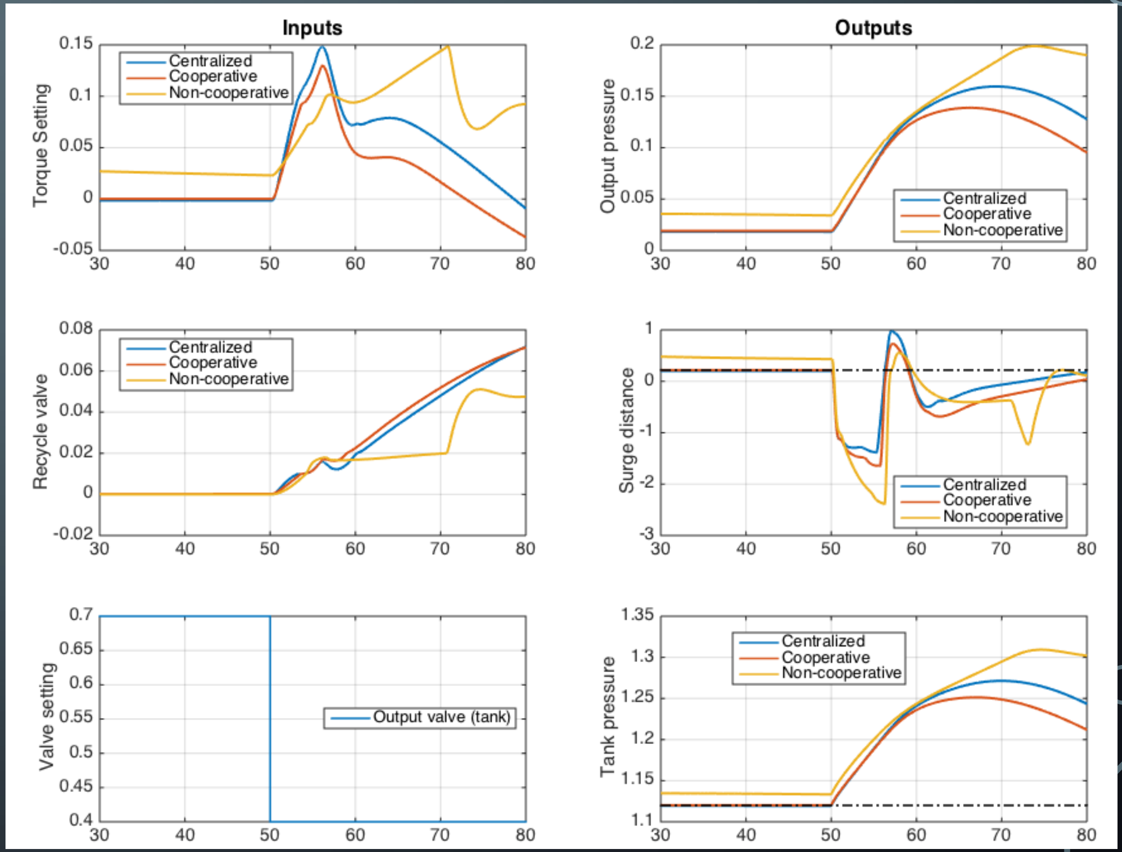
Cooperative unstable for $m \gtrsim 90$
Non-cooperative unstable for $m \gtrsim 120$

Cooperative unstable for $m \gtrsim 120$
Non-cooperative unstable for $m \gtrsim 170$

Results

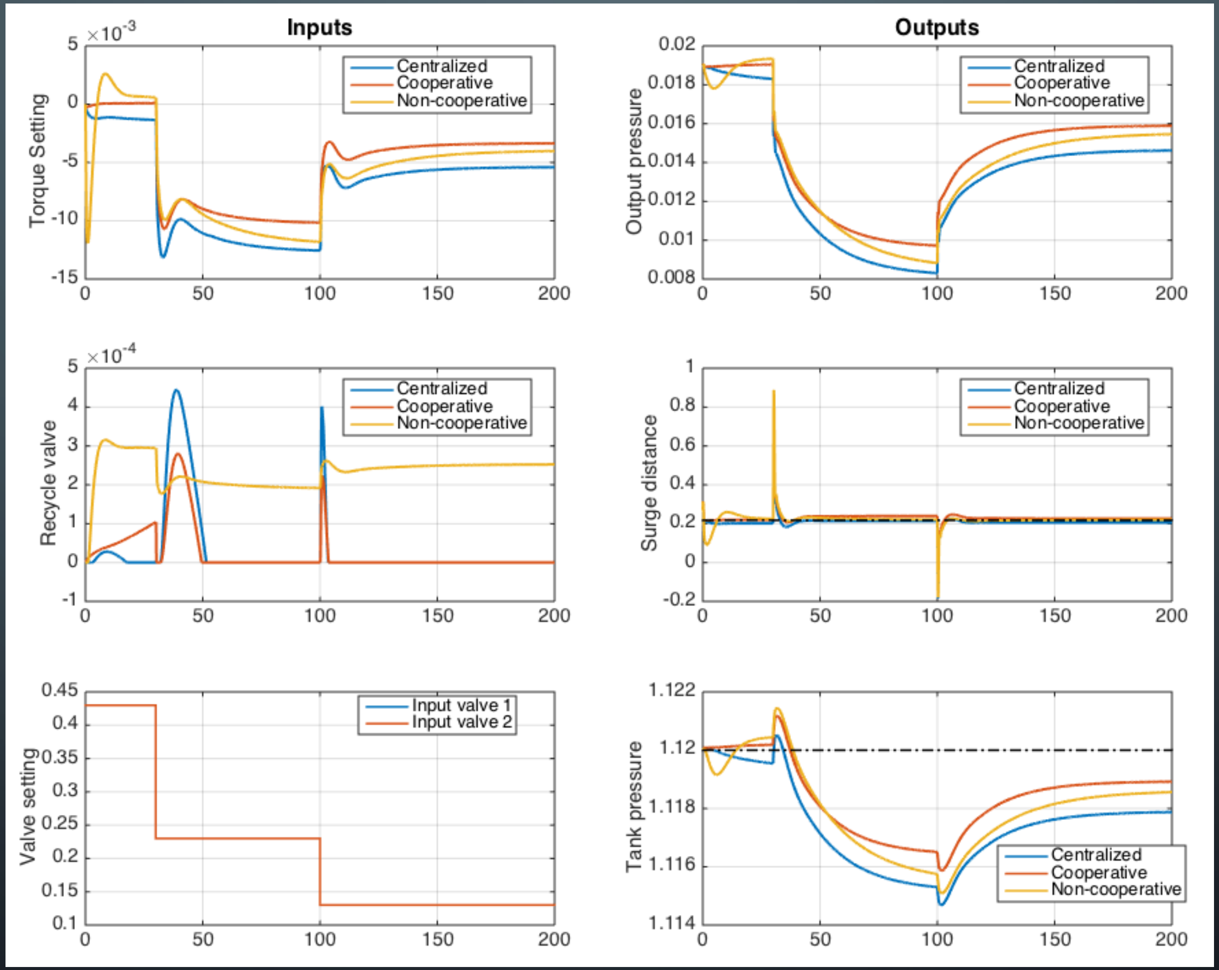
Output Disturbance





Results

Input Disturbances



Conclusion
Future Work

- Fine-tune controllers
- Implement individual observers for each compressor
- Quantify computational cost of each solution
  - How many iterations of decentralized are still cheaper than centralized solution?
- Compare results to industry standard (traditional control)
- Repeat process for serial network