Optimal Operation with Changing Active Constraint Regions using Classical Advanced Control

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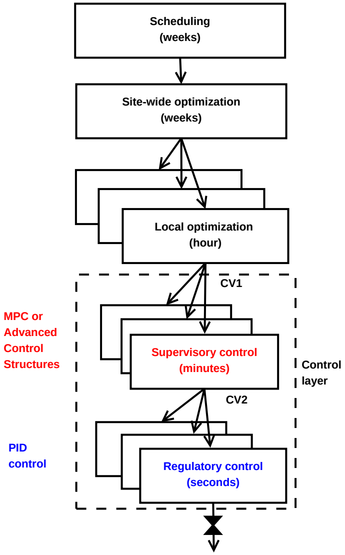
Outline

1. Control Hierarchy in a Process Plant

The control layer is divided into:

- Regulatory control



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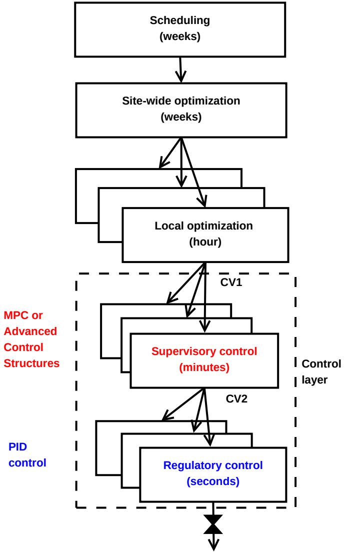
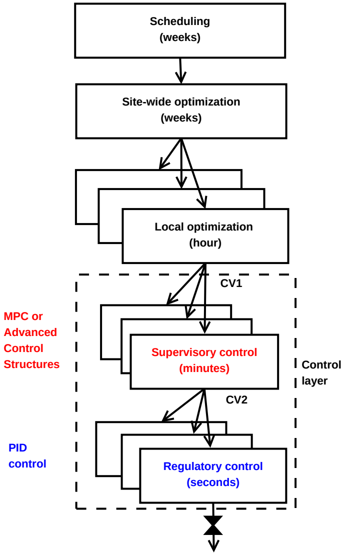
- Supervisory/advanced control



1. Control Hierarchy in a Process Plant

The control layer is divided into:

- Regulatory control
  - stable operation
- Supervisory/advanced control
  - follows the set points from long-term economic optimisation
  - calculates the set points for the regulatory layer



1.Optimal Operation

Objective function

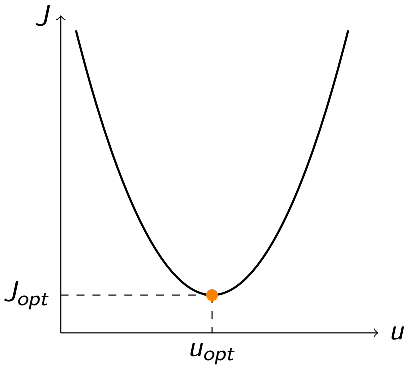
$\min_u J = J(u, x, d)$

s.t.

$f(u, x, d) = 0$

$g(u, x, d) \leq 0$

- f - model equations
- g - operational constraints
- u – degrees of freedom
- x – states
- d – disturbances



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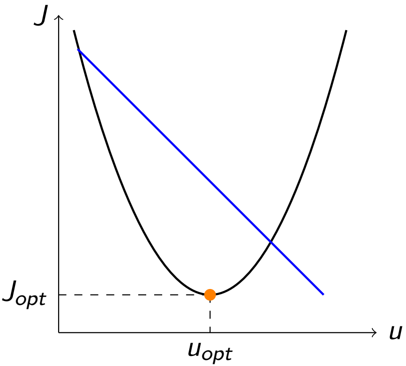

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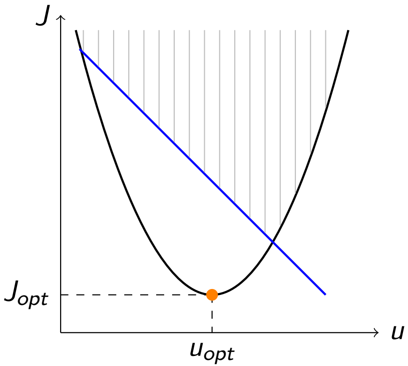

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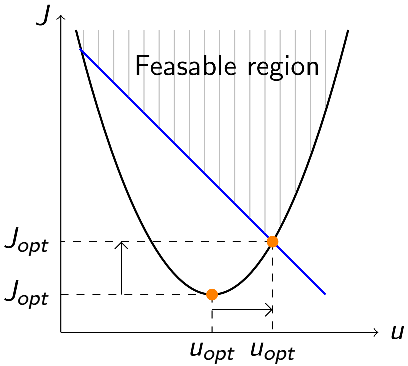

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MV constraints[1]

- valves, pumps

CV constraints[2]

- pressure,temperature

[1] Manipulated Variable
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- always control active constraints → control structure (pairing) depends on the operating region

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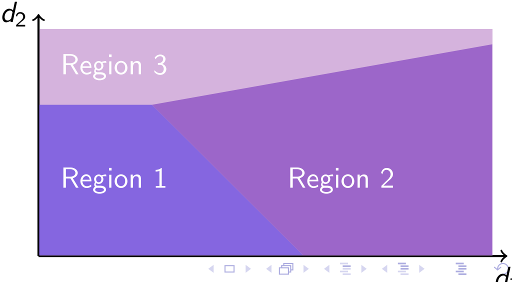

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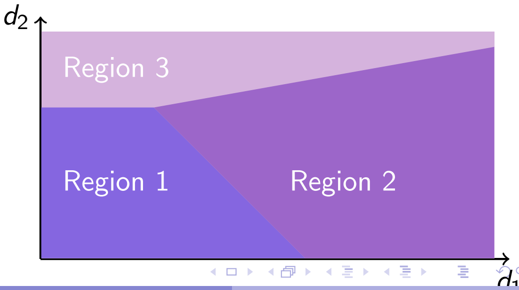

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- disturbances may change active constraint region (*space of active constraints*)
- how to ensure optimal operation with changing active constraint region in a systematic way?

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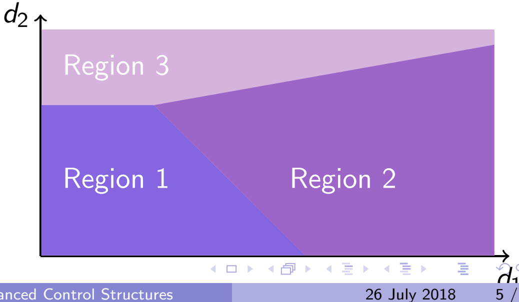

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[2] Controlled Variable

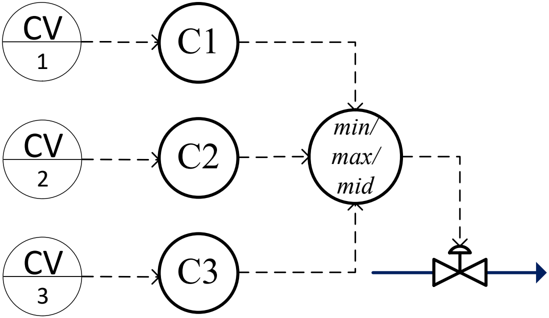
2.Classical Advanced Control Structures

- Cascade control
- Ratio control
- Decoupling
- Feed-forward
- Selectors
- Split range control (SRC)
- Valve position control (VPC)[1]

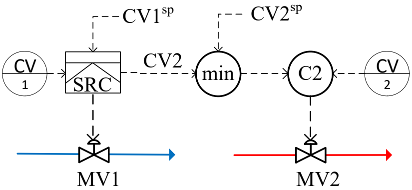
} can handle changes in active constraints (Selectors, SRC, VPC)

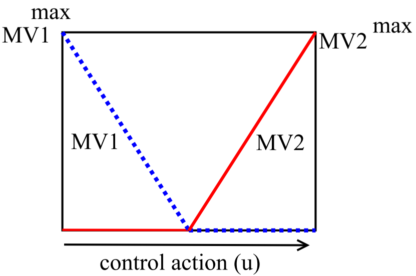
[1] Also known as Input Resetting or Mid-Ranging

2.Selectors for changes in active constraints

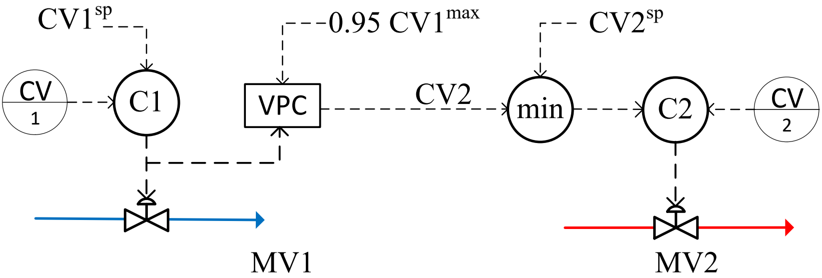


2. Split Range Control (SRC) for input constraints

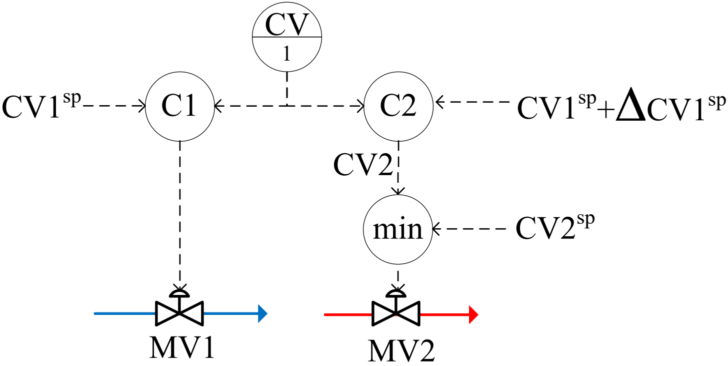




2. Valve Position Controller (VPC) for input constraints



2. Two Controllers with *min* selector as alternative to SRC



3.Optimal Operation using Advanced Control Structures
Proposed systematic procedure

Step 1 Define control objectives and priority list of constraints

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In *Step 1*.

If there are more CVs than MV $\rightarrow$

P1 MV inequality constraints $\rightarrow$ physical constraints

[1] variables that minimize the loss when kept constant in spite of disturbances

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- P2 CV inequality constraints $\rightarrow$ may be given up
- P3 MV or CV equality constraints $\rightarrow$ optimal operation

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- P4 Desired throughput (TPM) $\rightarrow$ give up at bottleneck

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- P2 CV inequality constraints $\rightarrow$ may be given up
- P3 MV or CV equality constraints $\rightarrow$ optimal operation
- P4 Desired throughput (TPM) $\rightarrow$ give up at bottleneck
- P5 Self-optimizing variables[1] $\rightarrow$ can be given up

[1] variables that minimize the loss when kept constant in spite of disturbances

3.Handling Constraints

In *Step 2*.

Input Saturation Pairing Rule

An important controlled variable (CV) (which cannot be given up) should be paired with a manipulated variables (MV) that is not likely to saturate.

MV Constraint

- If pairing rule was followed: give-up low priority CV.

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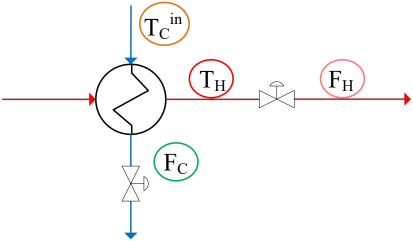
CV constraint

- Give-up low priority CV → min/max selector

4.Case study: Optimal Control of a Cooler
Control Objectives

Case study: Counter-current heat exchanger.

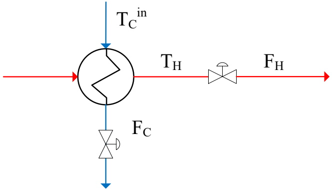
- important CV: Th
- less important CV (TPM): Fh
- MV: Fc
- disturbance: T_c^{in}



4. Priorities and Constraints

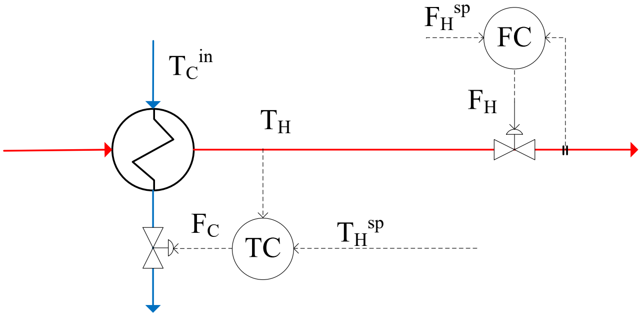
Define the priority list for step 1.

P1 $F_C \leq F_C^{max}$
P1 $F_H \leq F_H^{max}$
P2 $T_H = T_H^{sp}$
P3 $F_H = F_H^{sp}$



4. Pairing at the nominal operating point

Step 2 in the procedure



Pairing

- Use *Fc* to control *Th*.

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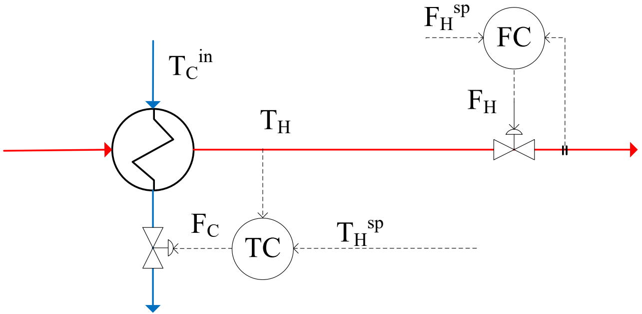
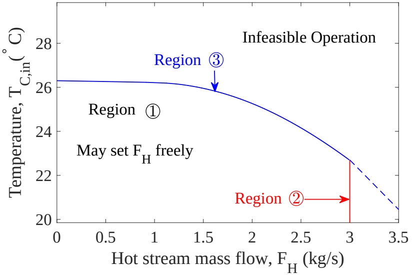


Pairing

- Use *Fc* to control *Th*.
- Impossible to use the input saturation pairing rule → *Fc* may saturate for a large T_c^{in}.

4. Active Constraints Regions



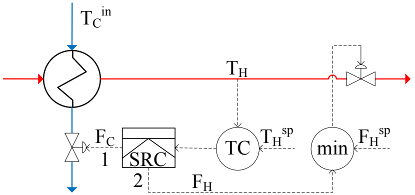
Active constraints in each region:

- Region 1: $F_H = F_H^{sp} < F_H^{max}$
- Region 2: $F_H = F_H^{sp} = F_H^{max}$
- Region 3: $F_C = F_C^{max}$

Task

Compare 3 alternatives Advanced Control Structures to handle a transition from Region 2 (the nominal operation point) to Region 3.

4. Alternative 1: Split Range Control



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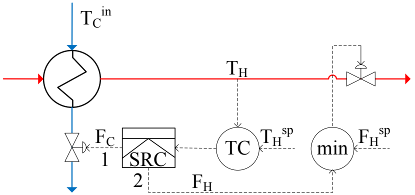

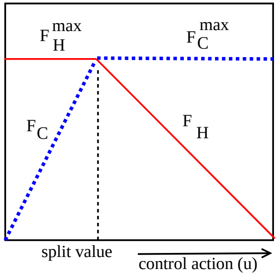

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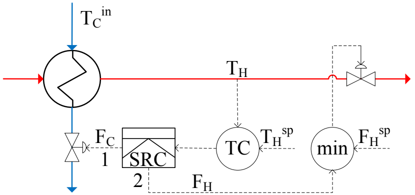
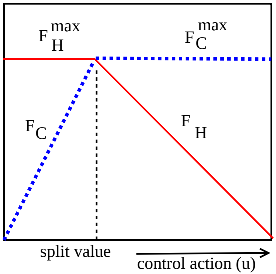
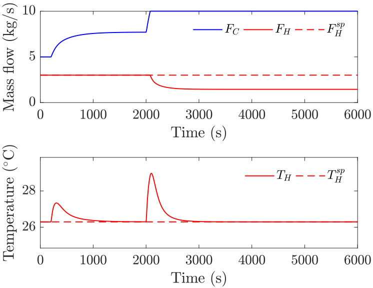
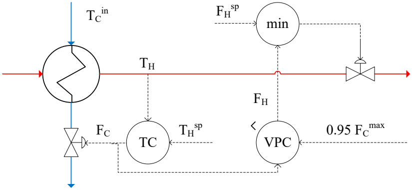






Optimal

4. Alternative 2: Valve Position Controller



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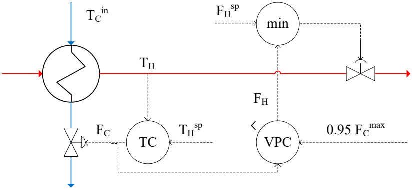
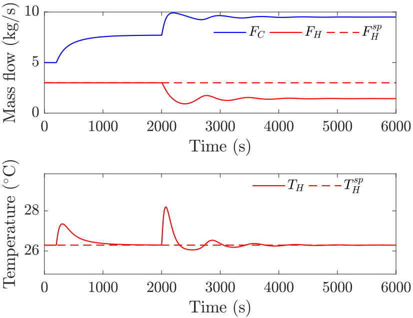
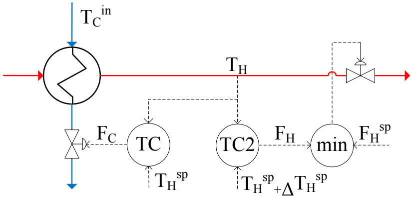




*(near-)*optimal

4. Alternative 3: Two Controllers



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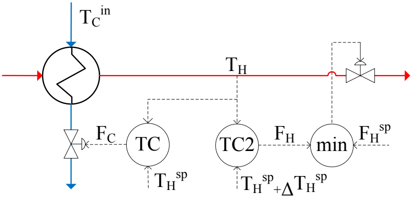

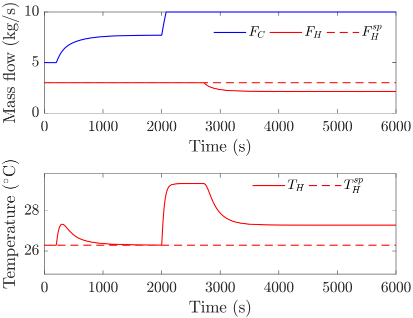

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Thank you!