Advanced process control

Sigurd Skogestad

2024

- ADVANCED PROCESS CONTROL (APC) module 2024
- Need to register in TKP4555 (module) or KP8115 (PhD)
- Ask for office space in K4, 2nd floor

- An introduction to the module is given
- **Wednesday 21 August 2024 10:30-11:00 in room K4.205 (2nd floor in building K4)**
- The rest of the semester the lectures/exercises are planned to be (I hope this is OK for everyone)
- **Wednesdays 09:15-12:00 in room K4.205**
- Lectures: Sigurd Skogestad (Professor)
- Exercises: Lucas Cammann (PhD student)
- Course contents:
- • **Learning outcome:** the students will be able to design plantwide control systems.
- • **Content:**
  - – Control structure design for complete chemical plants.
  - – Optimal economic operation
  - – Selection of economic controlled variables
  - * Active constraints
  - * Self-optimizing control
  - * Gradients as self-optimizing variables.
  - – Advanced regulatory control ("advanced PID control" = decomposition of the control systrem)
  - – Consistent inventory control.
  - – Tuning of PID controllers.
  - – Multivariable control
  - * Decentralized control and RGA.
  - * MPC (when should it be used)
  - – Real-time optimization (RTO)
  - * Feedback implementions
- • **Teaching activities:** Lectures, exercises, computer simulation.
- • **Course material**: Copies from scientific papers and books including
- * New paper (2023) on "Advanced control using decompotion and simple elements": https://folk.ntnu.no/skoge/publications/2023/skogestad-advanced-regulatory-control_arc/
- * Chapter 10 in Skogestad and Postlethwaite, "Multivariable Feedback Control, Wiley, 2010: https://folk.ntnu.no/skoge/book/ps/
- See also here for more information: https://folk.ntnu.no/skoge/vgprosessregulering/

Course information

- Lectures + industrial guest lectures (TBD)
  - Time: Wednesdays 09-11 (K4.205)
- 6 exercises + help sessions
  - Sessions : Wednesdays 11-12 (K4.205) ++
- Exercises count 20% of the grade of the module

Course Summary

This course is about how to operate and control complete chemical plants

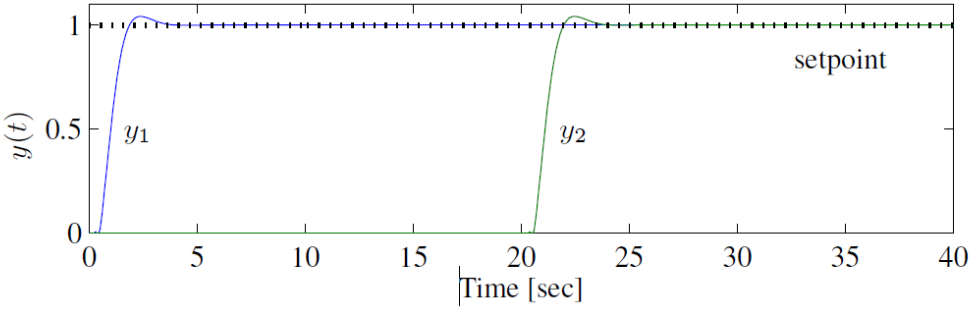
- Part 1 : Plantwide control
- Part 2 : Self-optimizing control
- Part 3 : PID tuning
- Part 4 : Inventory control and TPM
- Part 5: Superbisory control and switching
- Part 6 : ARC elements
- Part 7: More on switching and regulatory control
- Part 8: Extremum seeking control and RTO

NOTE

- «That something works doesn't mean that it couldn't be much better or simpler (PID), or even both better and simpler at the same time».
- Example: Sensor in wrong room

MULTIVARIABLE FEEDBACK CONTROL
Analysis and Design
Second Edition
Sigurd Skogestad
Norwegian University of Science and Technology
Ian Postlethwaite
University of Leicester

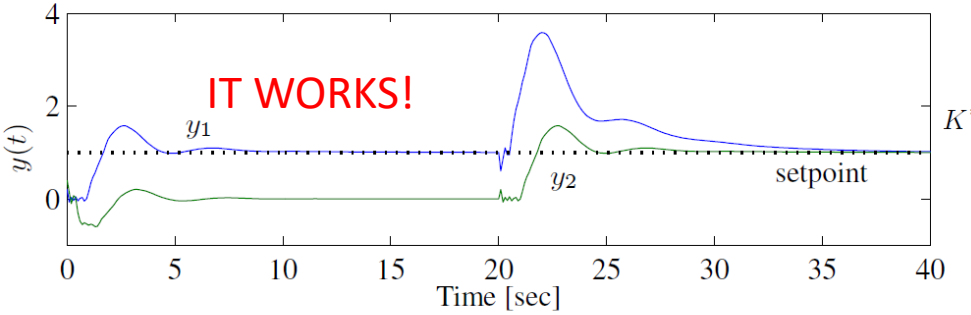
$$G = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$



$$K = \begin{bmatrix} \frac{1}{\tau_1 s} & 0 \\ 0 & \frac{1}{\tau_2 s} \end{bmatrix}$$

(a) Diagonal pairing; controller (10.51) with $\tau_1 = \tau_2 = 1$

$$= \begin{bmatrix} g_{12} & g_{11} \\ g_{22} & g_{21} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$



$$K^*(s) = \begin{bmatrix} \frac{-(0.5s+0.1)}{s} & 0 \\ 0 & \frac{(0.5s+2)}{s} \end{bmatrix}$$

$$G_{\text{sim}} = Ge^{-0.5s}.$$

(b) Off-diagonal pairing; plant (10.53) and controller (10.54)

Figure 10.15: Decentralized control of diagonal plant (10.50)

Part 1: Plantwide control

Introduction to plantwide control (what should we really control?)

Introduction

- Objective: Put controllers on flow sheet (make P&ID)
- Two main objectives for control: Longer-term economics (CV1) and shorter-term stability (CV2)
- Regulatory (basic) and supervisory (advanced) control layer

Optimal operation (economics)

- Define cost J and constraints
- Active constraints (as a function of disturbances)
- Selection of economic controlled variables (CV1). Self-optimizing variables.

Part 2: Self-optimizing control theory

- Active constraints
- Remaining Unconstrained degrees of freedom:
  - Ideal CV1 = Gradient (J_u)
  - Nullspace method
  - Exact local method
  - Link to other approaches
    - Gradient estimation methods
  - Examples

Part 3: PID tuning

PID controller tuning: It pays off to be systematic!

- Derivation SIMC PID tuning rules
  - Controller gain, Integral time, derivative time
- Obtaining first-order plus delay models
  - Open-loop step response
  - From detailed model (half rule)
  - From closed-loop setpoint response
- Special topics
  - Integrating processes (level control)
  - Other special processes and examples
  - When do we need derivative action?
  - Near-optimality of SIMC PID tuning rules
- Examples

Part 4: Regulatory («stabilizing») control

Inventory (level) control structure

- Location of throughput manipulator
- Consistency and radiating rule

Structure of regulatory control layer (PID)

- Selection of controlled variables (CV2) and pairing with manipulated variables (MV2)
- Main rule: Control drifting variables and "pair close"

Summary: Sigurd’s rules for plantwide control

Part 5

- Putting optimization into the control layer
- Supervisory control and switching

Part 6: Advanced control elements

Advanced control layer

- Design based on simple elements:
  - Ratio control
  - Cascade control
  - Selectors
  - Input resetting (valve position control)
  - Split range control
  - Decouplers (including phsically based)
  - When should these elements be used?
- When do we use MPC instead?

Case studies

- Example: Distillation column control
- Example: Plantwide control of complete plant Recycle processes: How to avoid snowballing

- Part 7: More on switching and inventory control
- Part 8: Transformed inputs

Course Plan 2024

Lecturer: Sigurd Skogestad (skoge@ntnu.no)
Exercises: Lucas Cammann (Lucas.Cammann@ntnu.no)
First lecture: Wednesday 21 August 10:30-12:00 in K4-205
Normal Lecture time: Wednesdays 09-12 in K4-205
Exercise: usually 11-12 the day of the lectures
Note, that the days of the lecture may change.

Week/Date	Lecture	Exercise
Week 34 / 21.08.	0. Introduction 1. Plant-wide control procedure	Exercise 1 out (2 weeks)
Week 35 / 28.08.	1. Continue 2. Self-optimizing control	
Week 36 / 04.09.	2. Self-optimizing control, continmue	Exercise 1 deadline Exercise 2 out (1 week)
Week 37 / 11.09.	3. Controller tuning	Exercise 2 deadline Exercise 3 out (1 week)
Week 38 / 178.09.	4. Inventory control and TPM 5. Supervisory control / switching	Exercise 3 deadline Exercise 4 out (2 weeks)
Week 39 / 25.10.	6. ARC elements	
Week 40 / 02.10.	7. More on switching and regulatory control	Exercise 4 deadline Exercise 5 out (2 weeks)
Week 41 / 09.10.	8. Transformed inputs / Guest lecture MPC	
Week 42 / 16.10.	9. Guest lecture Forsman	Exercise 5 deadline Exercise 6 out (2 weeks)
Week 43 / 23.10.		
Week 44 / 30.10.		Exercise 6 deadline

EXCEPTIONS 2024

- Wednesday 11.09 not available, I have booked the room K4.205 twice on **Monday 09.09**. One possible slot is 09-12, the other 1-3
- On September 18 you have booked the room the entire day for the Control Lab. I have booked **K4.438 on Monday 16** from 1-3
- October 9 not available, I have booked two slots: **Monday 07.10 9-12 and 1-3** in K4.205

There will be two guest lectures given by

- TBA: MPC application in Equinor
- Krister Forsman: Advanced process control in Perstorp