Optimal operation and advanced control using decomposition and simple elements

Sigurd Skogestad*

Krister Forsman*,**

*Department of Chemical Engineering
Norwegian University of Science and Technology (NTNU)
Trondheim
**Perstorp Co., Sweden

Tutorial workshop at Adchem Symposium
Toronto, 14 July 2024

Participants

CUSTOMER	ORGANIZATION	COUNTRY	EMAIL
Fikar, Miroslav	Slovak University of Technology	Slovakia	
Araujo Pimentel, Guilherme	University of Mons	Belgium	guilherme.araujopimentel@umons.ac.be
Jespersen, Stefan	Aalborg University	Denmark	sje@energy.aau.dk
Gareau-Lajoie, Antony	Polytechnique Montréal	Canada	antony.gareau-lajoie@polymtl.ca
Ganko, Krystian	Massachusetts Institute of Technology	United States of America	kkganko@mit.edu
Otto, Eric	Otto von Guericke University Magdeburg	Germany	eric.otto@ovgu.de

Tutorial (from webpage Adchem)

Optimal operation and advanced control using decomposition and simple elements

Summary.

How can you control a complex plant effectively using simple elements with a minimal amount of modelling? How can you put optimization into the control layer? Industry has been using simple and effective as "advanced regulatory control" schemes for almost 100 years. The objective of the workshop is to provide a systematic approach for designing such control systems. The approach is illustrated on numerous real industrial applications. The target audience includes both practicing control engineers as well as PhD students and teachers from academia.

Abstract:

More details about the workshop:

Control engineers rely on many tools, and although some people may think that in the future there will be one general universal tool that solves all problems, like economic model predictive control (EMPC), this is not likely to happen. The main reason is that the possible benefits of using more general tools may not be worth the increased implementation costs (including modelling efforts) compared to using simpler "conventional" advanced regulatory control (ARC) solutions. Economic optimization may be put into the control layer by using the magic of feedback to control the right self-optimizing variables, including economically active constraints.

Since its introduction in the 1940's, about 80 years ago, advanced regulatory control (ARC) has largely been overlooked by the academic community, yet it is still thriving in industrial practice, even after 50 years with model-based multivariable control (MPC). Examples of "advanced" control elements are cascade control, ratio control, selectors, anti-windup, split range control, valve position control (VPC), multiple controllers (and MVs) for the same CV, and nonlinear calculation blocks.

This workshop takes a systematic view on how to design a conventional ARC system. The starting point is usually optimal steady-state economic operation. The process may have many manipulated variables (MVs) for control (typically valves), but usually most of these are used to control "active" constraints, which are the constraints which optimally should be kept at their limits at steady state. For the remaining unconstrained degrees of freedom, we should look for self-optimizing variables, which are measured variables for which the optimal values depend weakly on the disturbances.

We usually start by designing a good control system for the normal (nominal) operating point, preferably based on single-loop PID controllers where each manipulated variable (MV), which is not optimally at a constraint, is paired with a controlled variable (CV). To handle interactions, disturbances and nonlinearity, one may add cascade control, ratio control, feedforward control, decoupling and more general calculation blocks. However, during operation one may reach new (active) constraints, either on MVs or CVs, which may be easily observed from measurements of the potential constraints. Since the number of control degrees of freedom does not change, we will need to give up the control of another variable. The key is then to know which variable give up, and it is shown how this in most cases may observed by feedback and implemented using standard ARC elements, including selectors and split range control.

Other extremely simple and powerful methods include nonlinear feedforward using input transformations and bidirectional inventory control. Both these methods go back to Greg Shinskey, who is well known to all older process control engineers, but they are in this workshop presented for the first time in a systematic way.

The theory is illustrated on many industrial case studies, including buffer management, heat exchangers, continuous reactors and distillation columns.

References

S. Skogestad, "Advanced control using decomposition and simple elements - An important and challenging research area". *Annual Reviews in Control*, **56**, 100903 (2023).

Forsman, K. (2016). Implementation of advanced control in the process industry without

the use of MPC. *DYCOPS conference, Trondheim, IFAC papers online*, *49*(7), 514–519.

About the presenters

Sigurd Skogestad received his Ph.D. degree from the California Institute of Technology, Pasadena, USA in 1987. He has been a full professor at Norwegian University of Science and Technology (NTNU), Trondheim, Norway since 1987. He is the principal author, together with Prof. Ian Postlethwaite, of the book "Multivariable feedback control" published by Wiley in 1996 (first edition) and 2005 (second edition). His research interests include the use of feedback as a tool to make the system well-behaved (including self-optimizing control and stabilization), limitations on performance in linear systems, control structure design and plantwide control, interactions between process design and control, and distillation column design, control and dynamics. His other main interests are mountain skiing (cross country), orienteering (running around with a map) and grouse hunting. He is a Fellow of both the American Institute of Chemical Engineers (2012) and IFAC (2014) and is a member of the Process Automation Hall of Fame (2011).

Krister Forsman got his Ph.D. degree from Linköping University, Sweden, in 1990. He has worked in the chemical and pulp and paper industries since 1994. Since 2005 he is Corporate Specialist in Process Control at Perstorp Specialty Chemicals. He has worked with around 50 plants in some 20 countries. In 2006 he published a text book in process control for practitioners. Since 2012 he is part time Adjoint professor at NTNU, dept of Chemical Engineering. Here, his research is focused around plant wide control concepts and applications of control structures.

About Sigurd Skogestad

- 1955: Born in Flekkefjord, Norway
- 1956-1961: Lived in South Africa
- 1974-1978: MS (Siv.ing.) studies in chemical engineering at NTNU
- 1979-1983: Worked at Norsk Hydro co. (process simulation)
- 1983-1987: PhD student at Caltech (supervisor: Manfred Morari)
- 1987-present: Professor of chemical engineering at NTNU
- 1994-95: Visiting Professor UC Berkeley
- 2001-02: Visiting Professor UC Santa Barbara
- 1999-2009: Head of ChE Department, NTNU
- 2015-..: Director SUBPRO (Subsea research center at NTNU)

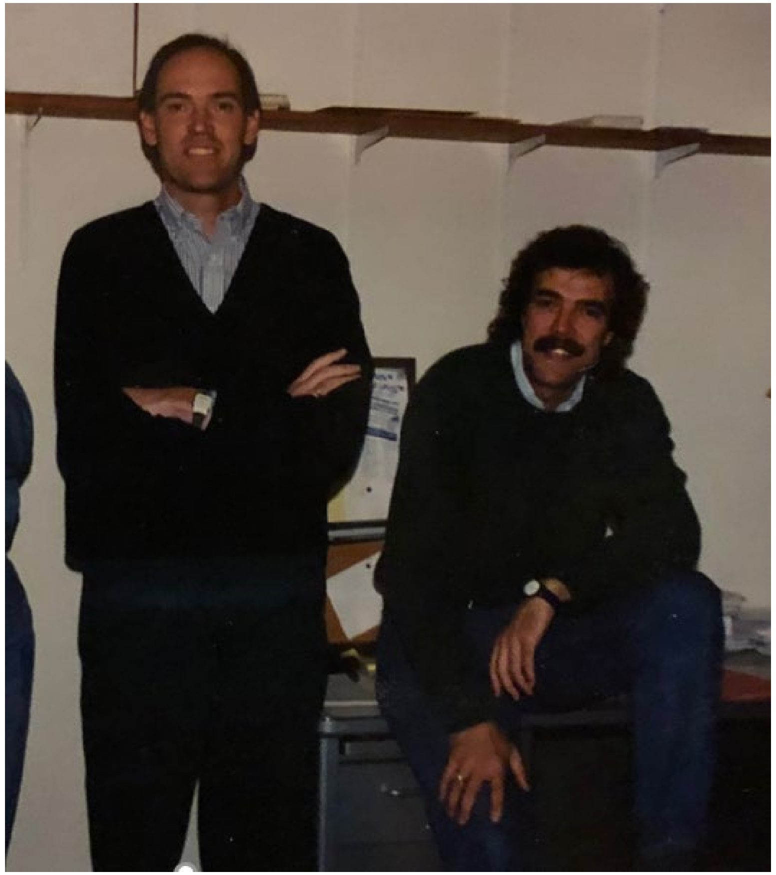
Non-professional interests:

- **mountain skiing (cross country)**
- **orienteering (running around with a map)**
- **grouse hunting**

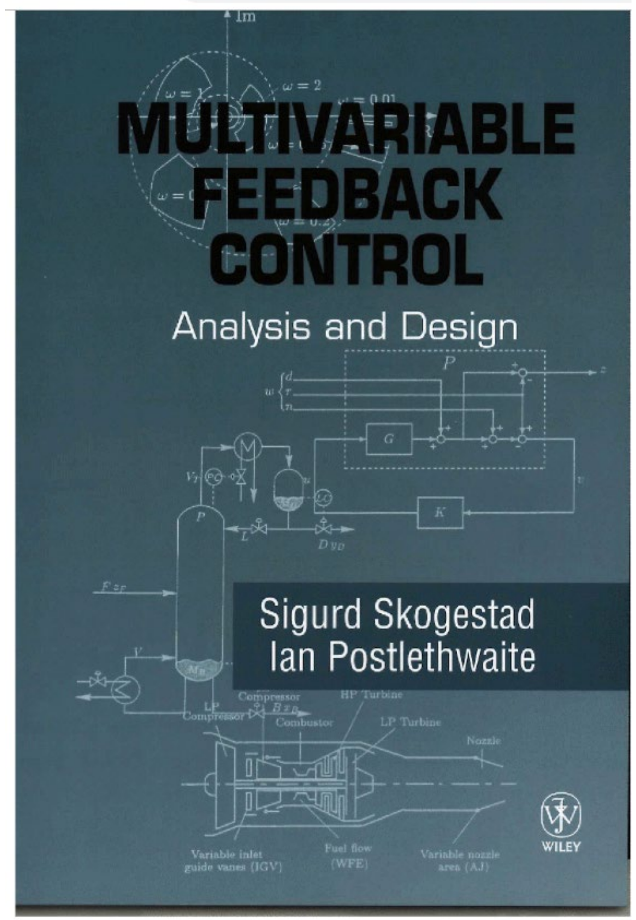
About Krister Forsman

- 1963: Born in Stockholm, Sweden
- MSc in Applied Mathematics, 1987
- PhD in Control Theory, Linköping 1991
- ABB Corporate Research, Lund and Malmö, 1994-1999
- ABB Industrial Systems, Malmö, 1999-2001
- ABB Australia, 2001-2002
- ABB Process Industries, 2002-2003
- Self employed: Reglerdoktorn AB, 2003-2005
- Perstorp Specialty Chemicals, 2005-
- NTNU [20%] Adjunct Professor, 2012-

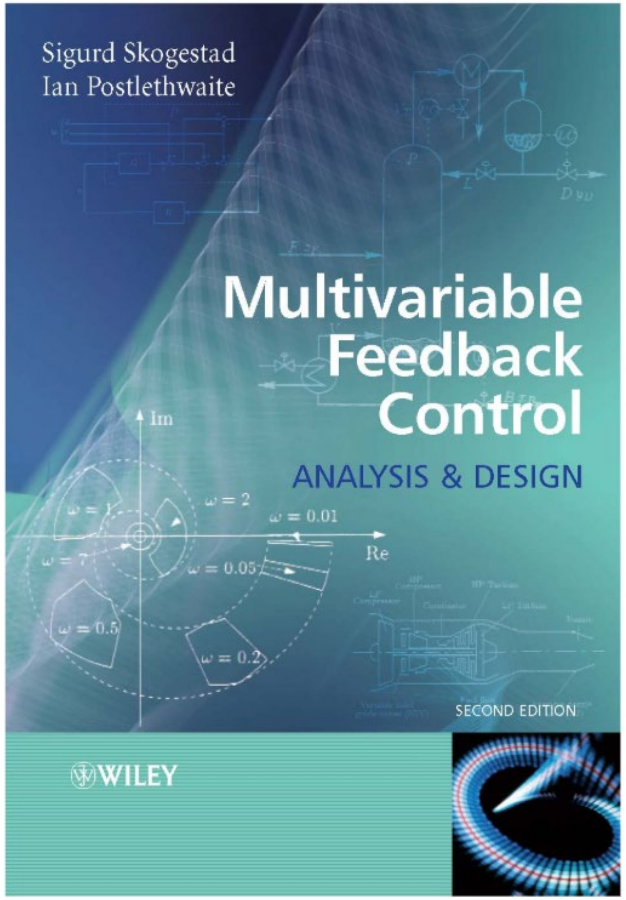
Robust multivariable control



Berkeley, Dec. 1994

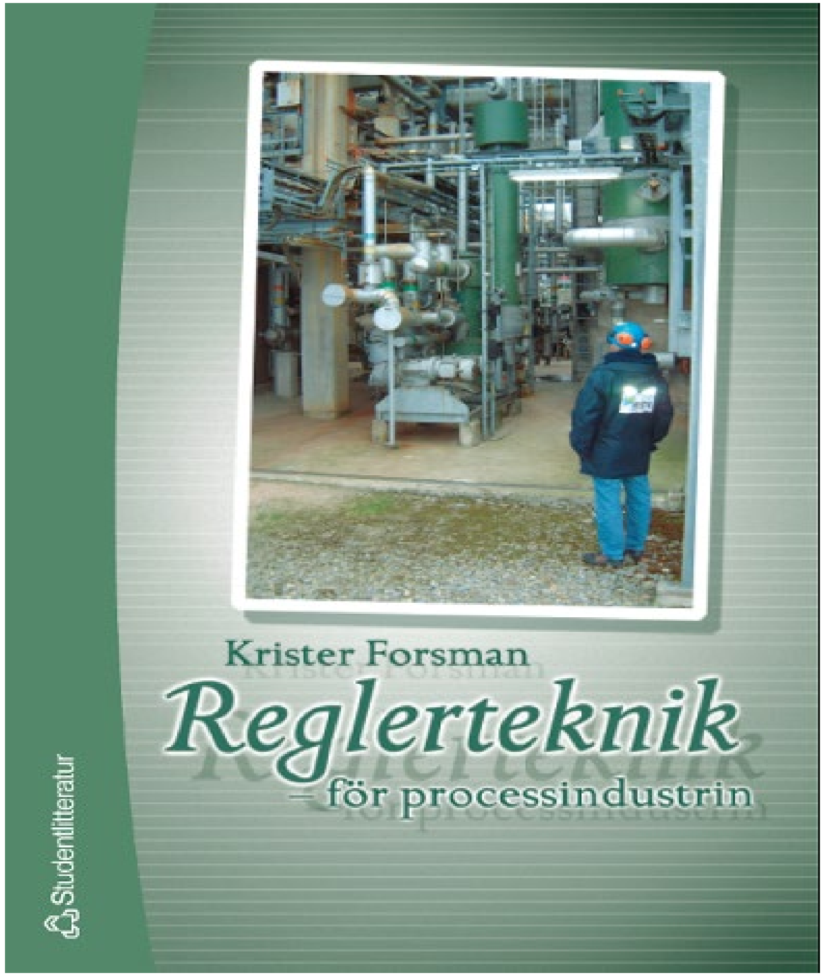


1996



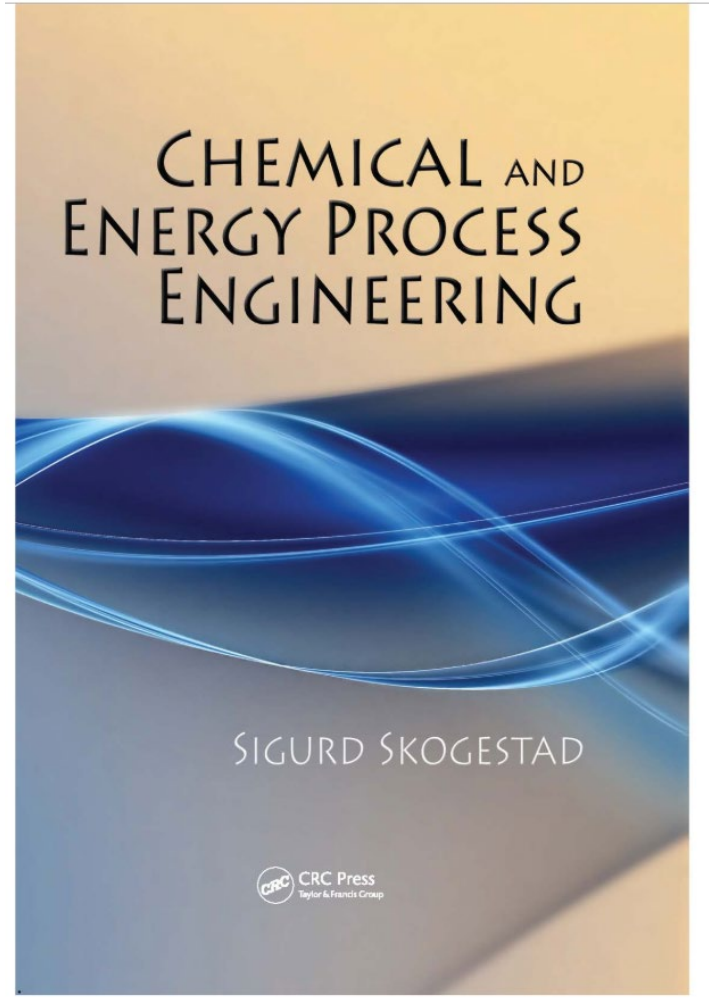
2005

Krister’s control book (2005) (unfortunately, only in Swedish)



Process engineering

2000, 2003, 2009



2009

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Review article

Advanced control using decomposition and simple elements

Sigurd Skogestad

Department of Chemical Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

ARTICLE INFO

Keywords:
Control structure design
Feedforward control
Cascade control
PID control
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Override control
Time scale separation
Decentralized control
Distributed control
Horizontal decomposition
Hierarchical decomposition
Layered decomposition
Vertical decomposition
Network architectures

ABSTRACT

The paper explores the standard advanced control elements commonly used in industry for designing advanced control systems. These elements include cascade, ratio, feedforward, decoupling, selectors, split range, and more, collectively referred to as “advanced regulatory control” (ARC). Numerous examples are provided, with a particular focus on process control. The paper emphasizes the shortcomings of model-based optimization methods, such as model predictive control (MPC), and challenges the view that MPC can solve all control problems, while ARC solutions are outdated, ad-hoc and difficult to understand. On the contrary, decomposing the control systems into simple ARC elements is very powerful and allows for designing control systems for complex processes with only limited information. With the knowledge of the control elements presented in the paper, readers should be able to understand most industrial ARC solutions and propose alternatives and improvements. Furthermore, the paper calls for the academic community to enhance the teaching of ARC methods and prioritize research efforts in developing theory and improving design method.

Paper is open access and is also available on my home page (search for “skogestad”)

https://folk.ntnu.no/skoge/

Chemical Engineering

Sigurd Skogestad Professor

Department of Chemical Engineering, Norwegian University of Science and Technology (NTNU), N7491 Trondheim, Norway

Start here...

- About me - CV - Powerpoint presentations - How to reach me - *Email: skoge@ntnu.no*
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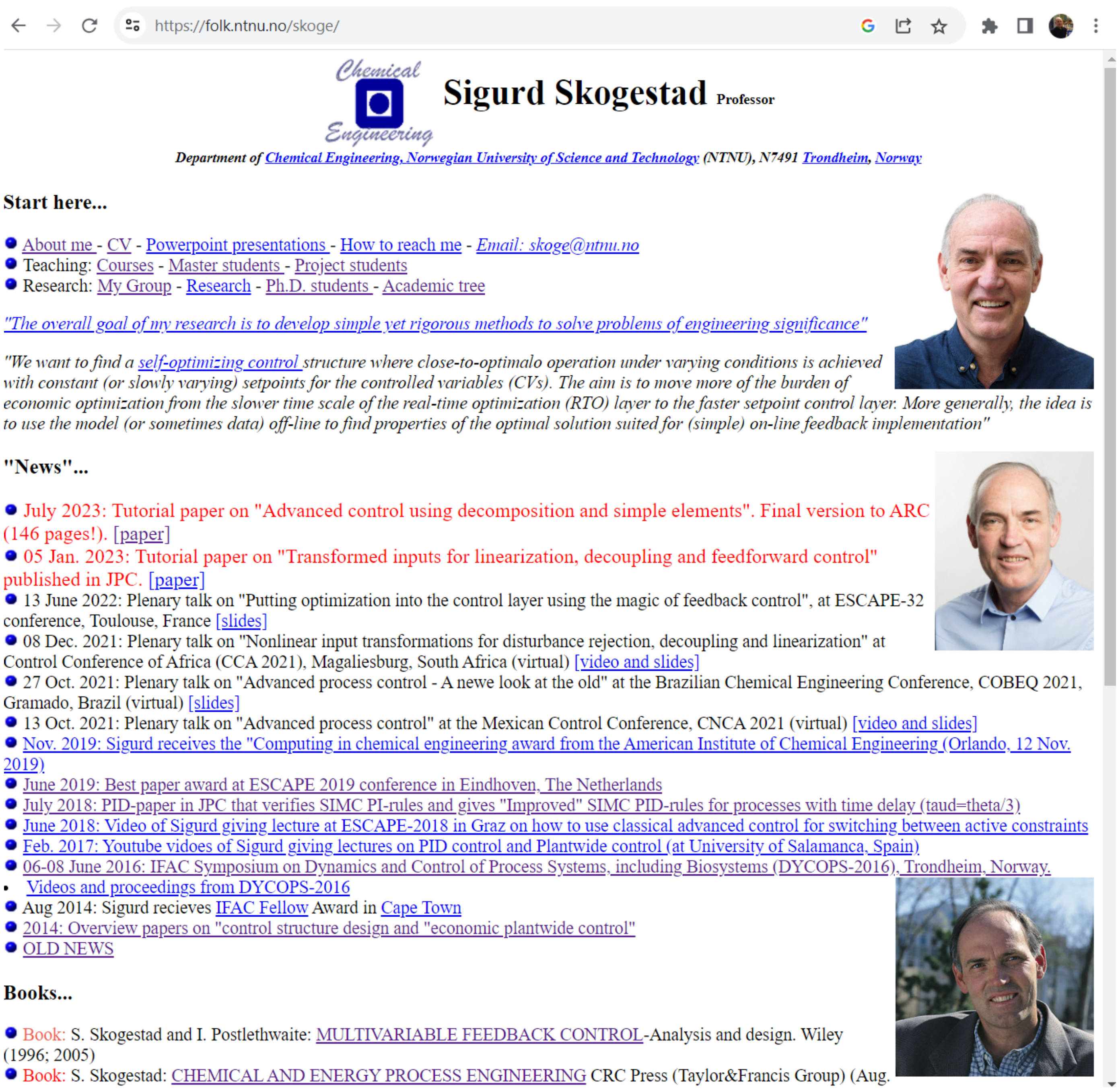
- Research: My Group - Research - Ph.D. students - Academic tree

"The overall goal of my research is to develop simple yet rigorous methods to solve problems of engineering significance"

"We want to find a self-optimizing control structure where close-to-optimalo operation under varying conditions is achieved with constant (or slowly varying) setpoints for the controlled variables (CVs). The aim is to move more of the burden of economic optimization from the slower time scale of the real-time optimization (RTO) layer to the faster setpoint control layer. More generally, the ide to use the model (or sometimes data) off-line to find properties of the optimal solution suited for (simple) on-line feedback implementation"

"News"

"The goal of my research is to develop simple yet rigorous methods to solve problems of engineering significance"



08:00	Coffee/tea and registration
08:30 08:45 09:30 10:00 10:30 11:30 12:00	Introduction Part 1: Introduction to APC. The three main inventions of process control. Brief on PID tuning Industrial applications (From this week: FC, FF. Ask: Alternative? (Ratio) Part 2: Optimal operation (hierarchy), CV selection, cascade, time scale separation . Pairing rules. Coffee break Par.t 3: Standard control elements: Selectors, split range, VPC, controllers with different setpoints. Industrial applications: Cascade…. + +
12:30	Lunch (60 min)
13:15 14:00 14:30	Part 3: Standard control elements, continued Part 4: Inventory control and optimal buffer management, Industrial applications: Water case from Stenungsund ++
15:00	Break (30 min)
15:30	More industrial applications (Quiz: How keep ratio when MV saturates?)
17:30	End of workshop (but note that England-Spain starts at 15:00)
18:00	Welcome reception