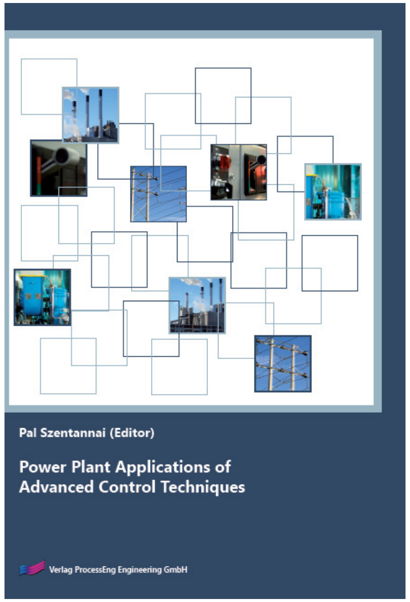
10th International Conference on
HEAT ENGINES AND ENVIRONMENTAL PROTECTION
Balatonfüred, 23-25 May, 2011

Book Presentation Session

Power Plant Applications of Advanced Control Techniques

Publisher: ProcessEng, Vienna ISBN: 978-3-902655-11-0 Editor: Pal Szentannai



1. **Publishing house ProcessEng and its scientific book series**
   Dr. habil. Maximilian Lackner
2. **Why and how to apply advanced control in power plants?**
   Dr. Pál Szentannai
3. **Advances in coordinated control**
   Dr. Jenő Kovács

Why and how to apply advanced control in power plants?

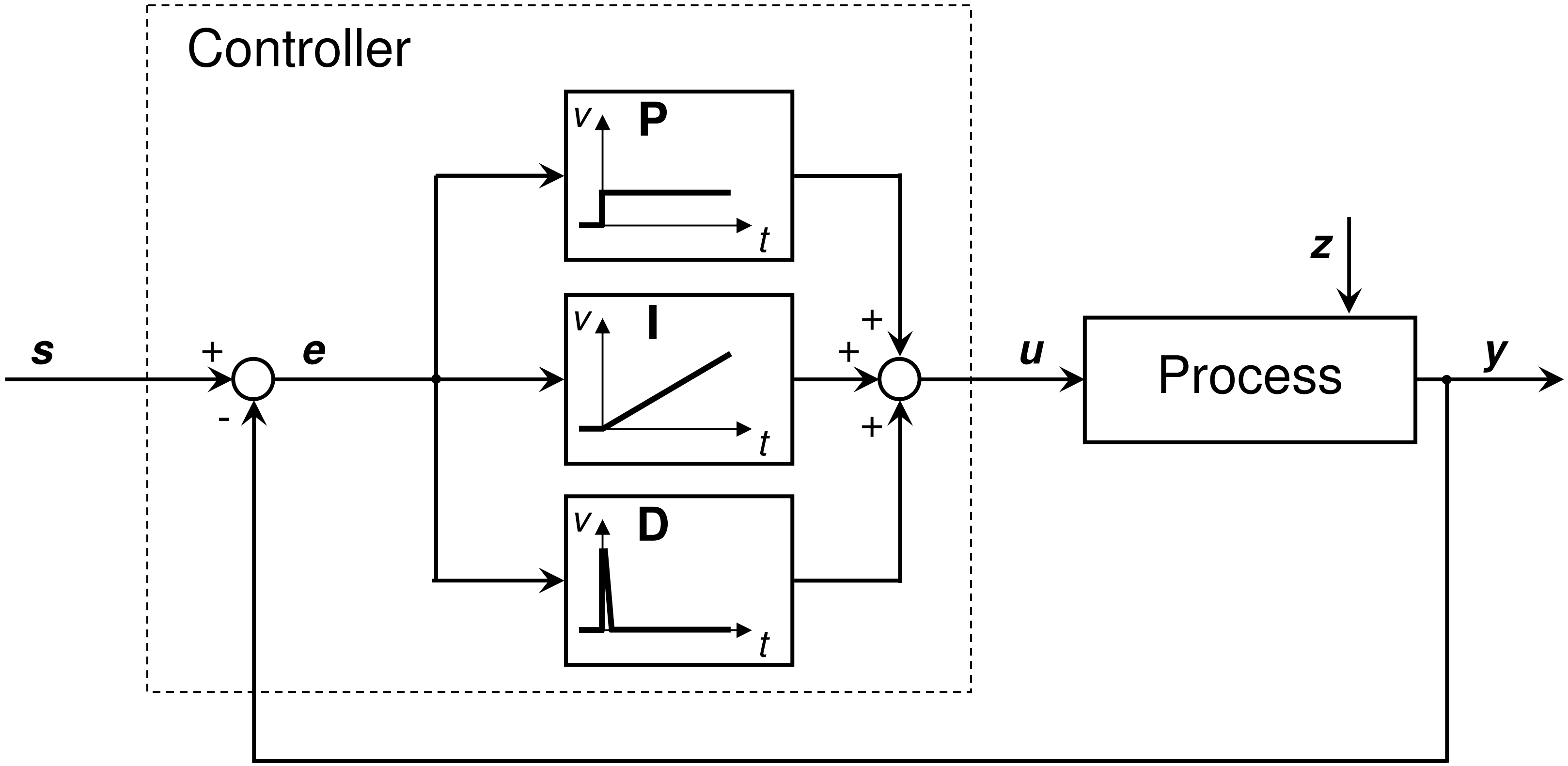
Dr. Pál SZENTANNAI

Introduction

1. Advanced control techniques
2. Why apply ... ?
3. How to apply ... ?
4. Application examples

Summary

1. Advanced Control Techniques
The PID controller as the classical solution



- Simple operation
- Perceptible meaning of the 3 parameters
- The practically exclusively used technique

1. Advanced Control Techniques

The most important groups

- Soft Sensor
- Gain Schedule
- Multi Mode

for nonlinear processes

- Loop Decoupling

advanced extensions also to classical control

- MPC (Model Predictive Control) ← most often used
- DMC (Dynamic Matrix Control) ← subset of MPC
- Fuzzy
- Neural Network

„intelligent" methods

1. Advanced Control Techniques

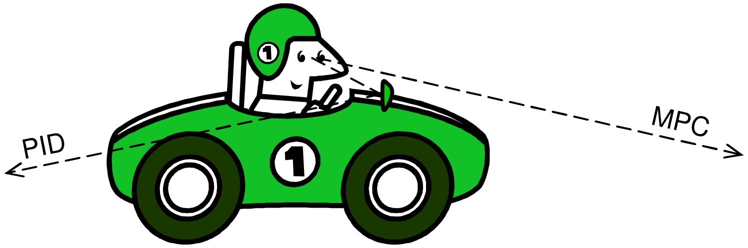
1.1. MPC (Model Predictive Control)

- Process model $\xrightarrow{u} \boxed{y = f(u,x,\ldots)} \xrightarrow{y}$
- Setpoint $s(n \cdot t_n)$
- Constraints $\leq, \ldots$
- Cost function $Q \cdot (s-y)^2 + R \cdot u^2 \;\rightarrow\; \min$

to be solved $\leftarrow$ quadratic problem with constraints
$\leftarrow$ at each sampling (on-line)
the first control to be applied to the process

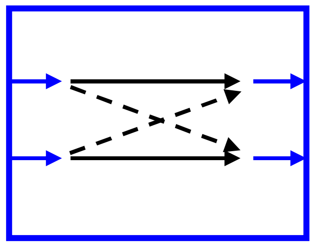
1. Advanced Control Techniques
1.1. MPC (Model Predictive Control)
Advantages

- Considers future values



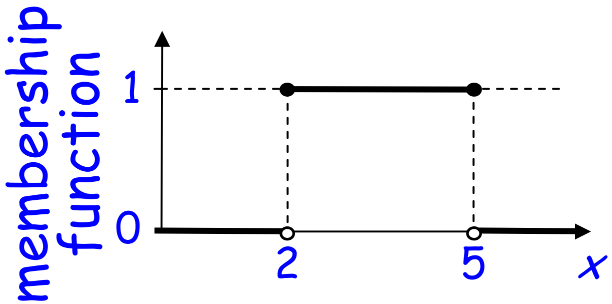
- Considers constraints

- MIMO application available

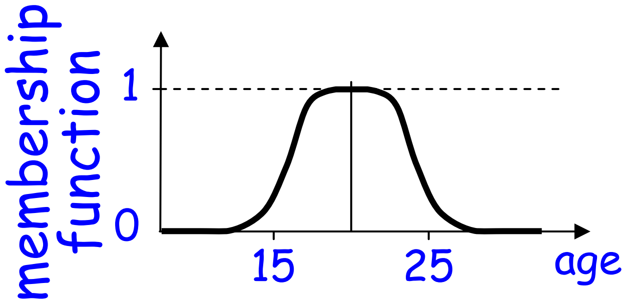


1. Advanced Control Techniques
1.2. Fuzzy

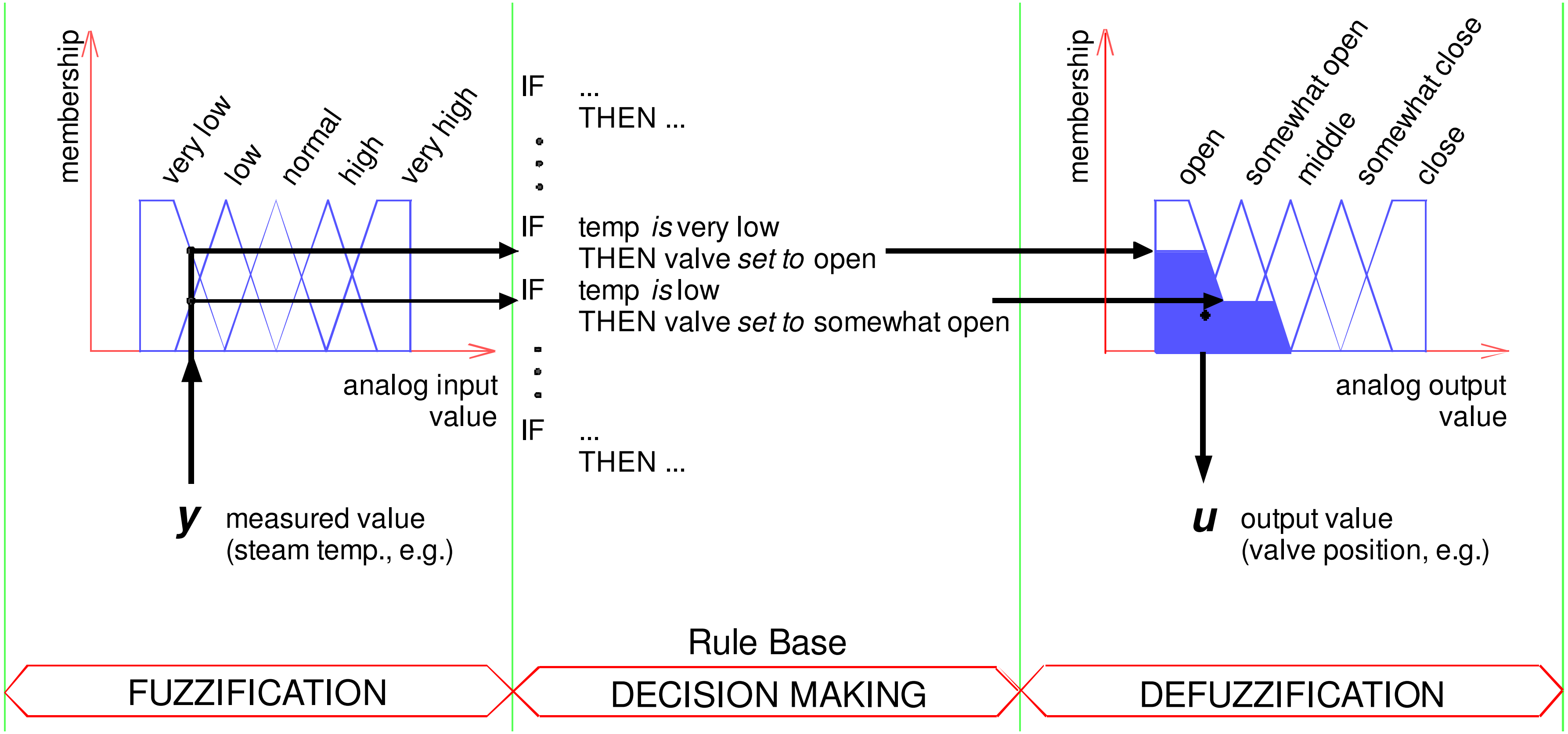
Classical set: $2 \leq x \leq 5$



Fuzzy set: youth



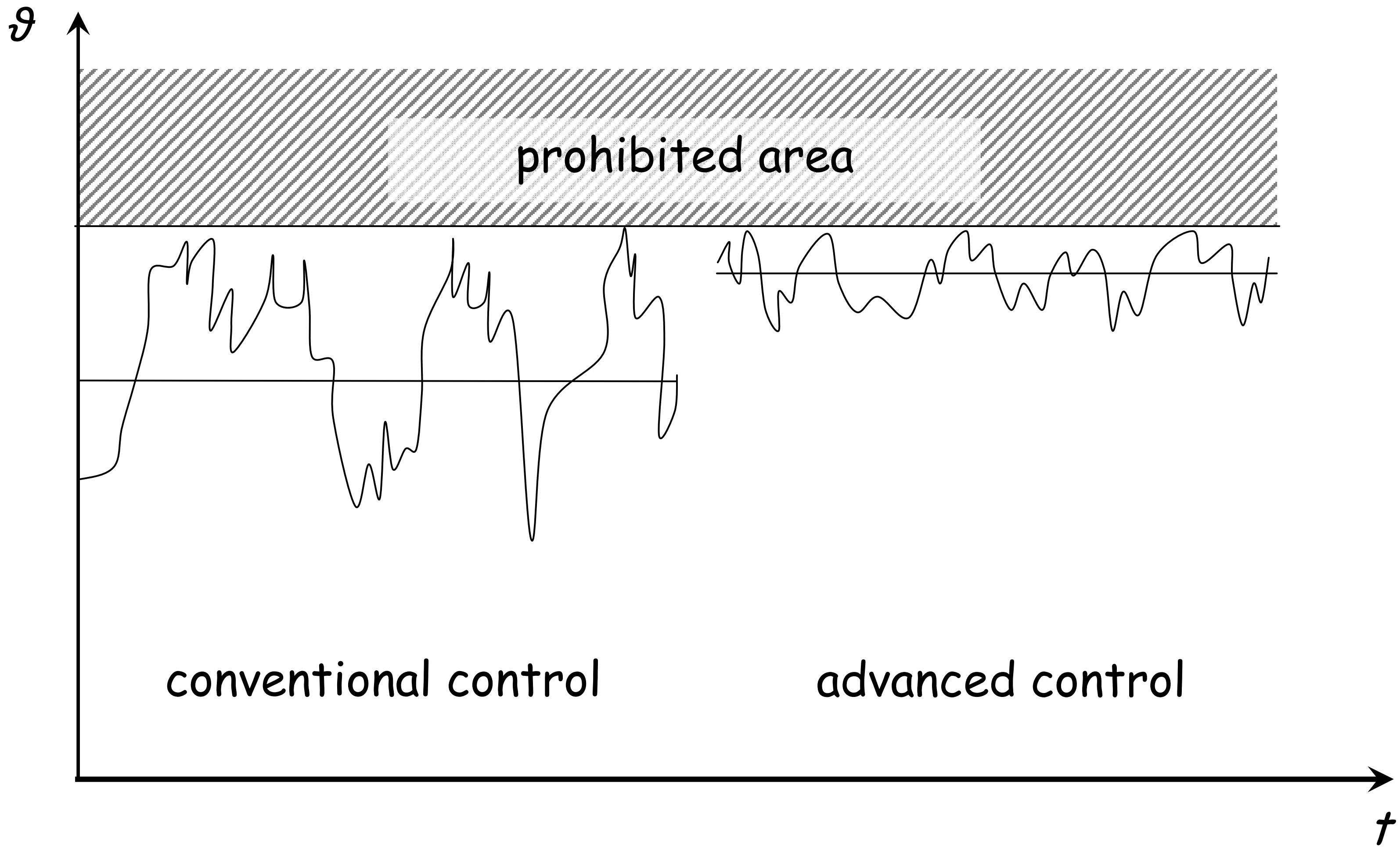
1. Advanced Control Techniques
1.2. Fuzzy Control



+ Easy realization of human / expert knowledge
+ Low-cost applications (computer, sensor, actuator)
- Unsmooth output
- Stability ??

2. **Why apply** advanced control in power plants?

Just for economic / environmental benefit!



2. Why apply ... ?

- Reaching higher efficiency in steady states (which directly means lower fuel costs and emission – as introduced in the example above).
- Expanding the limits of steady state operations.
- Making dynamic changes smoother and less resource-consuming. (This covers start-up, shut-down and load change periods. In the first two cases the sped up processes directly result in savings in fuel cost, while considering and limiting thermal stresses also results in an increased life-time.)
- Increasing the level of supply by making the power plant a more flexible one in the energy market.

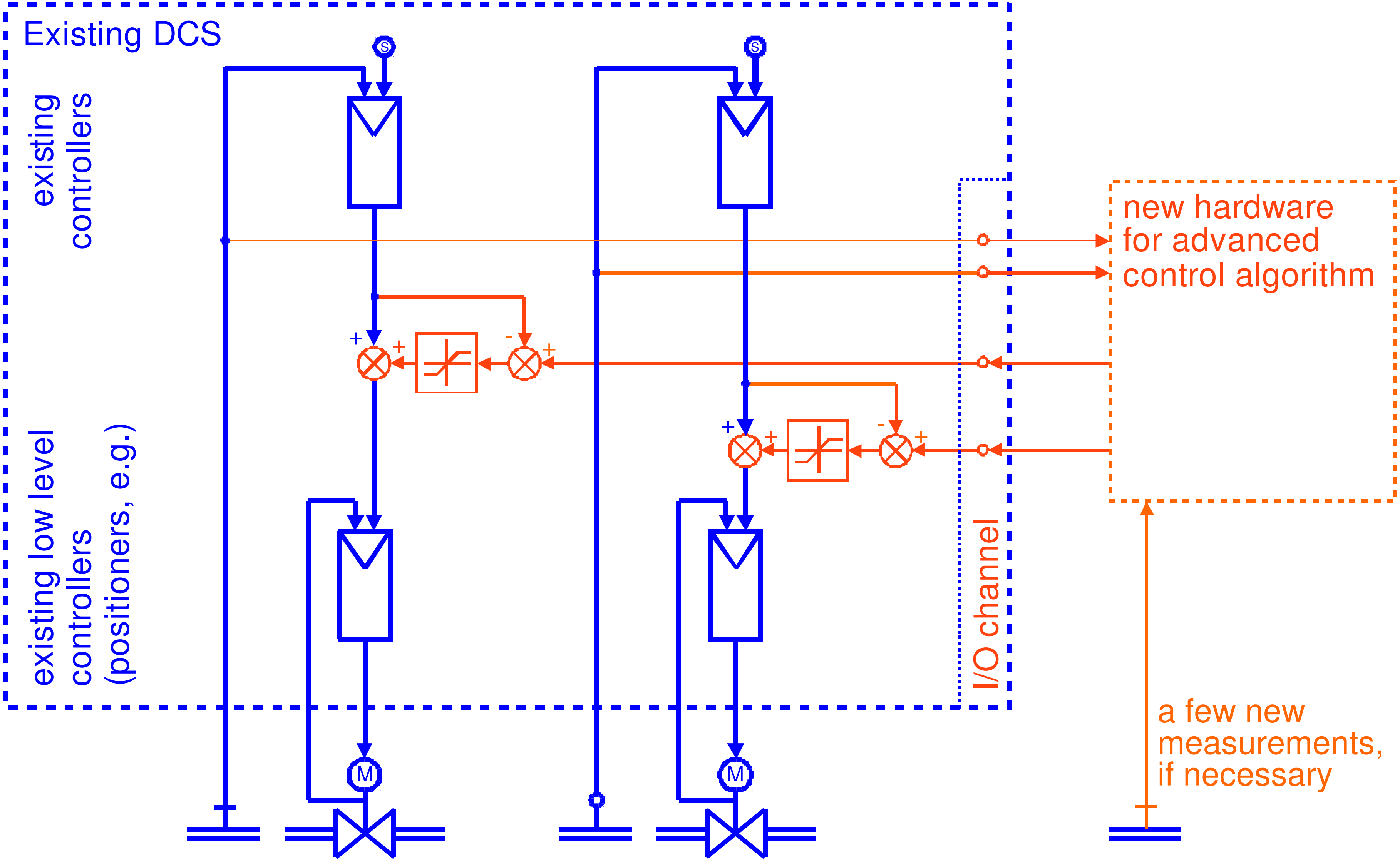
2. Why apply ... ?

Advanced control techniques: **industrial applications**
Example: Model Predictive Control

	1995	**1999**	**2005**
Refining	67.2%	55.7%	49.2%
Petrochemicals	13.0%	15.3%	9.9%
Chemicals	8.5%	4.6%	15.6%
Pulp and paper	2.0%	1.9%	3.8%
Polymer	n.a.	1.1%	6.3%
Air & Gas	n.a.	1.6%	5.9%
Food Processing	0.5%	1.5%	3.5%
Mining/Metallurgy	0.7%	1.0%	1.5%
Power plants	n.a.	n.a.	0.2%
Furnaces	1.9%	1.1%	n.a.
Cement	n.a.	n.a.	1.3%
Unclassified	4.2%	16.1%	2.7%
Total Number of Applications	2,233	4,635	9,456

Dittmar

3. How to apply advanced control in power plants?



- New / Running plants: traditional control: supervisor
- Running plant: external platform necessary

4. Application examples (book chapters)

Chap-ter	Page No.	1st author, Affiliation	Coun-try	Power Plant	Process	Control technique	Test
C1	17	**Lemos**, INESC-ID/IST	PT	thermal	superheated steam temp.	adaptive MPC	field
C2	43	**Havlena**, Honeywell	CZ	thermal	combustion	MPC	field
C3	69	**Kovács**, Foster Wheeler	FI	thermal	energy balance + condensate throttling	coordinated control	field
C4	89	**Tan**, North China Electric Power Univ.	CHN	thermal	boiler-turbine unit	PID decoupling nonlin. anal.	field
C5	113	**Ruusunen**, Univ. Oulu	FI	thermal	combustion	soft sensor for PI	field
C6	135	**Sanchez-Lopez**, Inst. Investigaciones Eléctricas	MEX	thermal	steam temp.	DMC & fuzzy	model
C7	163	**Ikonen**, Univ. Oulu	FI	thermal	sec. air	Markov chains	model
C8	181	**Gilbertson**, Univ. Bristol	UK	thermal	bed pressure	advanced p-measurement	lab
C9	209	**Garduno-Ramirez**, Electrical Research Inst.	MEX	thermal	el. power, st. pressure, drum l.	fuzzy gain scheduling + loop decoupling	model
C10	257	**Kocaarslan**, Istanbul Univ.	TR	thermal	el. power, st. enthalpy	adaptive	field
C11	273	**Costa**, INESC-ID/IST	PT	solar furnace	shutter	adaptive	model
C12	295	**Henriques**, Univ. Coimbra	PT	solar	oil temp.	neural network	field
C13	321	**Pickhardt**, Univ. Buchs	CH	solar	oil temp.	MPC & fuzzy	field
C14	345	**Lemos**, INESC-ID	PT	solar	oil temp.	adaptive predictive	field
C15	361	**Roncero-Sánchez**, Univ. Castilla-La Mancha	ESP	wind, PV	active and reactive power	state-feedbk. & predictive-integral & predict.-repet.	model
C16	393	**Camblong**, ESTIA	FR	wind	speed, pitch	robust	model
C17	427	**Gruber**, Univ. Sevilla	ESP	fuel cell	oxygen excess ratio	MPC	lab
C18	453	**Cam**, Kirikkale Univ.	TR	hydro	power system	fuzzy gain-scheduled PI	model

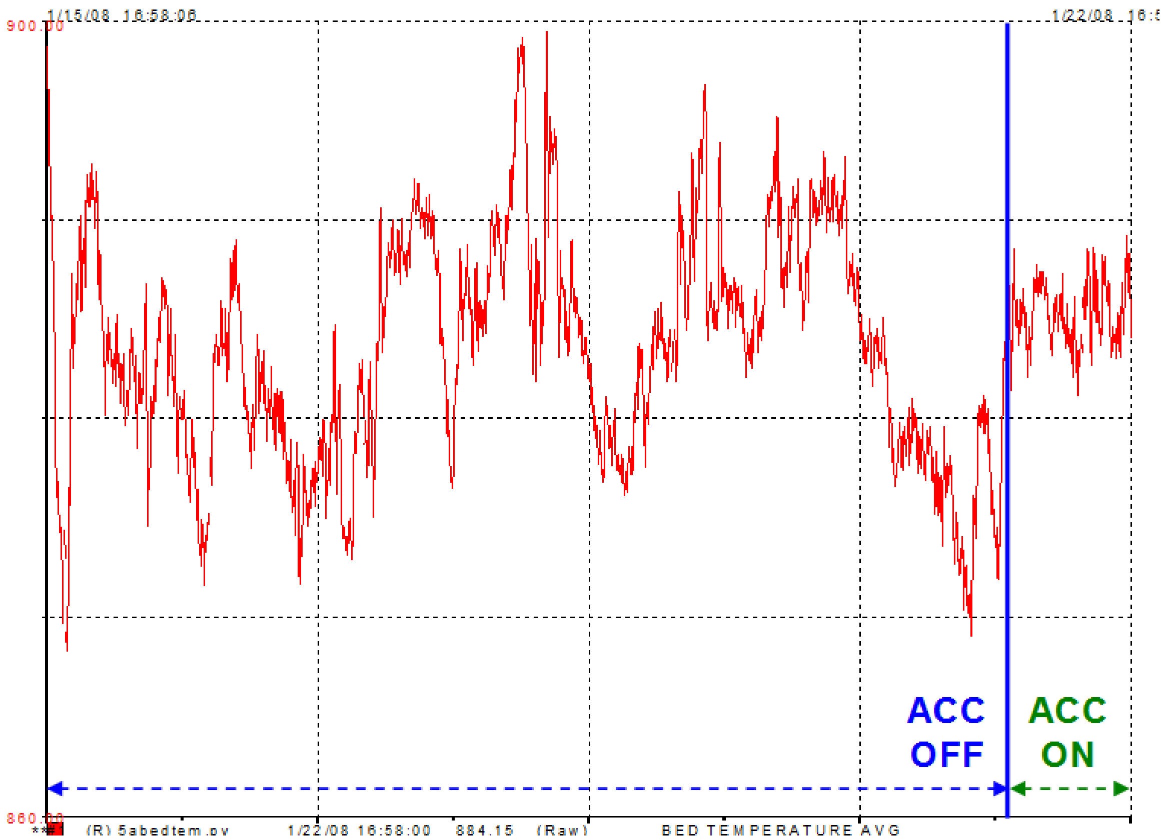
4. Application examples

4.1. MPC combustion control of a CFBC

Simple transfer matrix of the modeled system:

		Fuel feed (manipulated input)	Air feed (manipulated input)	Heating value (disturbance input)
		$F(s)$	$A(s)$	$H(s)$
Thermal power (output)	$Q_s(s)$	0	$\frac{kmH}{\tau_Q s+1}$	$-\frac{kmA_0}{\tau_Q s+1}$
Bed tempera-ture (o.)	$T_B(s)$	$\frac{Hc_2}{s(\tau_B s+1)}$	$-\frac{c_2 kmH}{s(\tau_B s+1)}$	$\frac{c_2 kmA_0}{s(\tau_B s+1)}$
Fuel mass (output)	$m(s)$	$\frac{1}{s}$	$-\frac{kmH}{s}$	$\frac{kmA_0}{s}$

4. Application examples
4.1. MPC combustion control of a CFBC – **results**



Boiler bed temperature control 7-day trend;
6 days with standard PID controls, last day with ACC switched on.

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4. Application examples
4.1. MPC combustion control of a CFBC – **results**

The implementation of the closed-loop advanced control on top of existing DCS PID controls significantly improved operations of the 310 t/h circulating fluidized bed boilers 5A and 5B of the Jinshan Power Plant at SINOPEC Shanghai Petrochemical Company.
The most significant benefits include reduced variability of the bed temperature from 860 – 900 °C to required set point around 885 °C with the standard deviation less than 1 °C; controlled SO_x emissions with standard deviation less than 25 mg/m^3; reduced flue gas O_2 emissions to 2.5% resulting in boiler efficiency increase by 0.25 - 0.5% point; improved boiler responsiveness to load demand changes, resulting in ability of the boilers to maintain key process variables (flue gas O_2, bed temperature, SO_2 emissions) stabilized within load step changes up to 40 – 50 t/h.

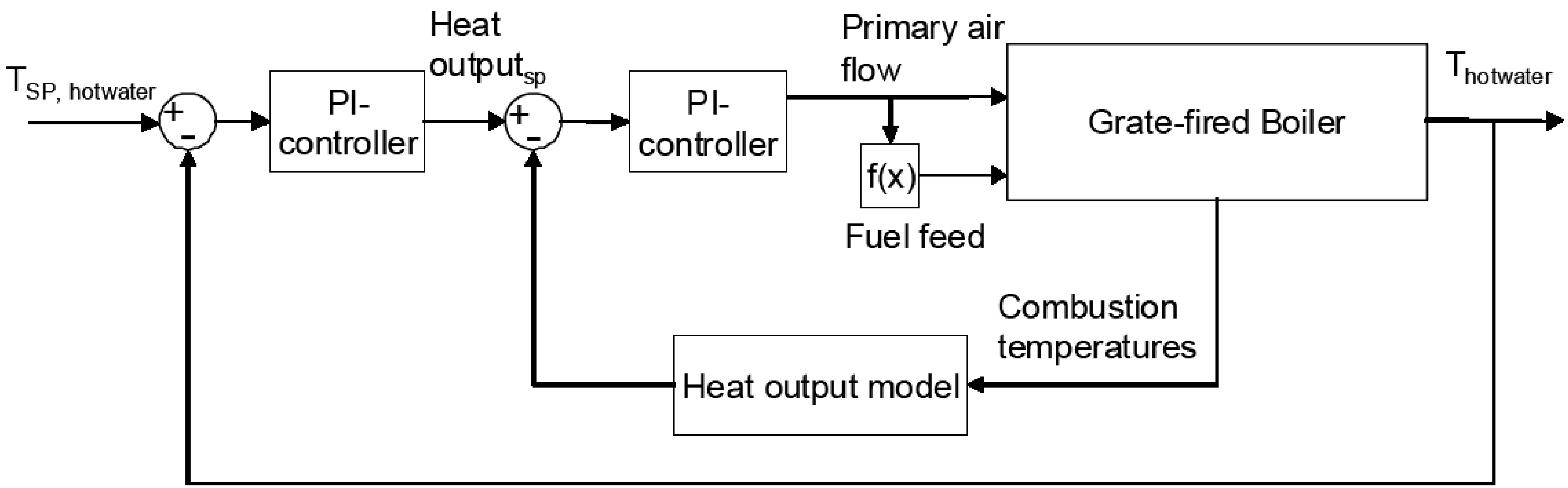
4. Application examples

4.2. Primary air of a 300 kW boiler

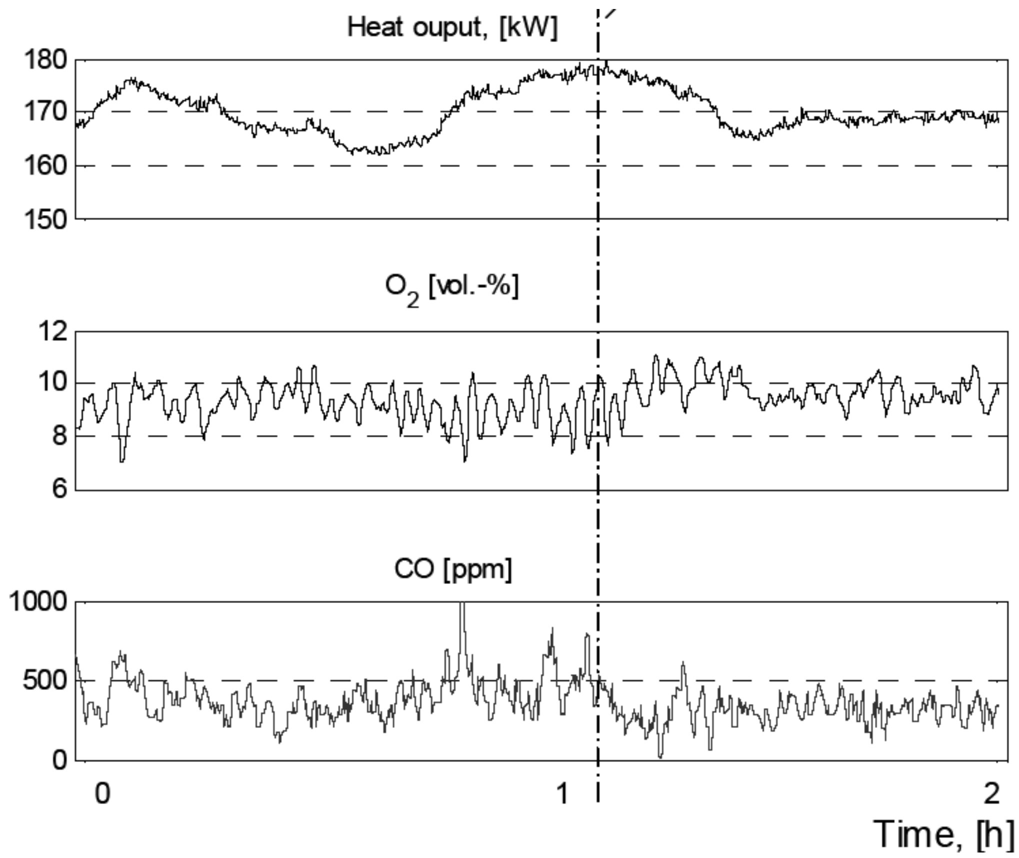
<u>Process:</u> small-scale grate-fired boiler for solid biomass fuels / combustion power control

<u>Problem:</u> inhomogeneous fuel quality + varying fuel feeding → combustion power fluctuations

<u>Control strategy:</u> process model (ARX) gives fast forecast towards traditional internal control loop

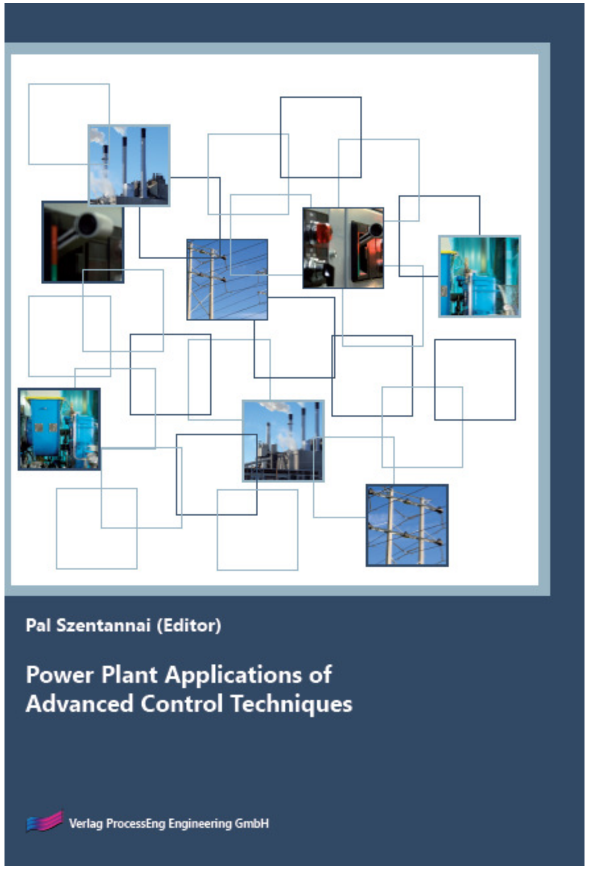


4. Application examples
4.2. Primary air of a 300 kW boiler – **results**



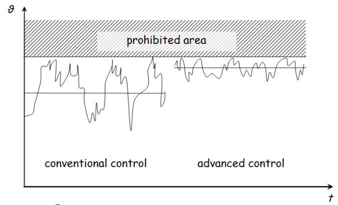
- Fluctuation (standard deviation) of heat output and CO ↘ 40%
- CO concentration ↘ 25%
- Fluctuation (standard deviation) of O_2 ↘ 45%
- Combustion efficiency ↗ 0.4 percent point

Why and how to apply advanced control in power plants?

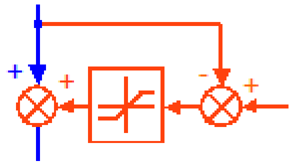


1. Advanced control

2. Why ? – Economic benefit



3. How ? – Supervisor



4. Examples

$\eta \nearrow 0.4$ % point

Thank you for your attention!

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