A Plantwide Control Procedure with Application to Control Structure Design for a Gas Power Plant

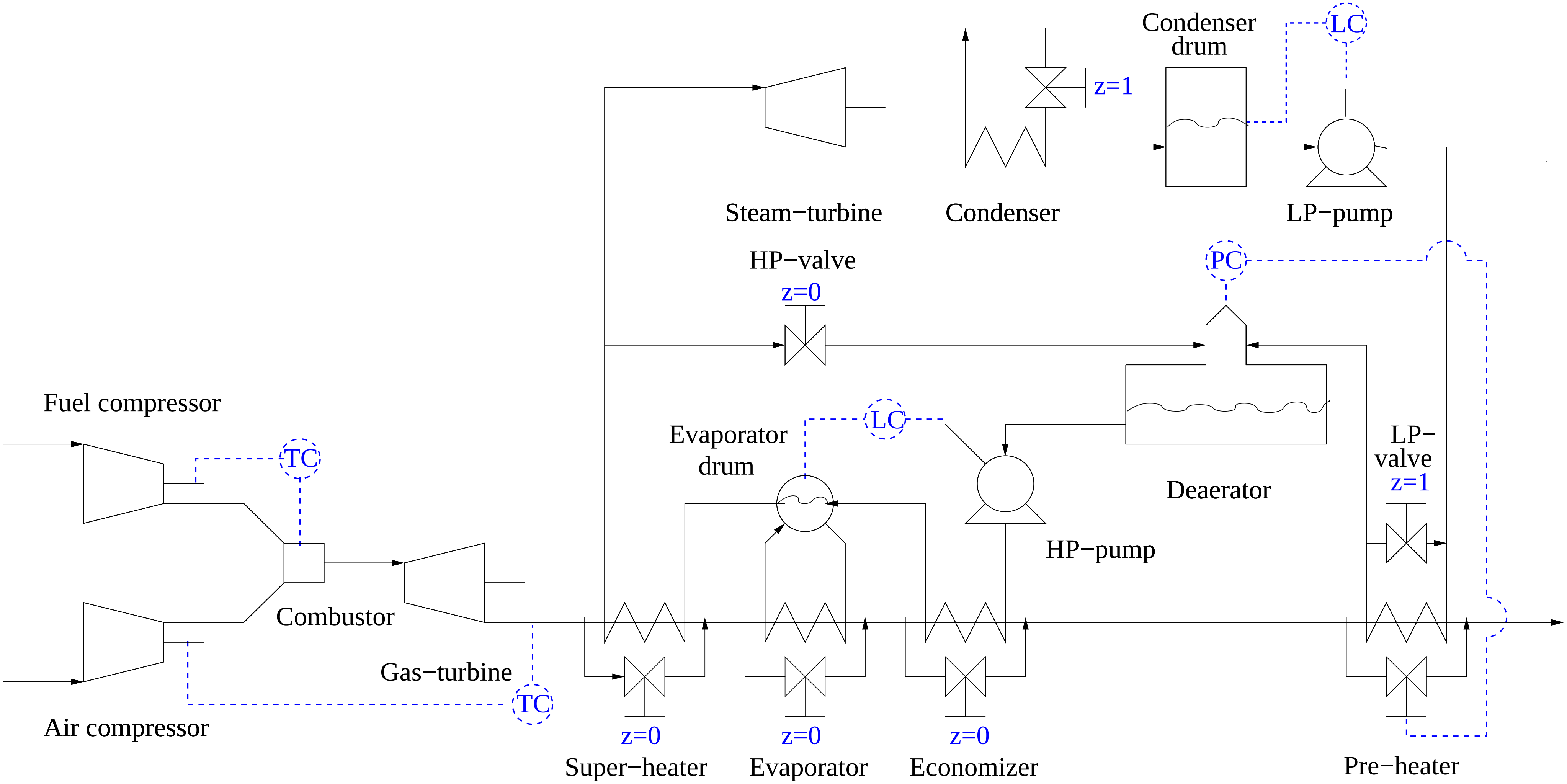
S. Skogestad, M. S. Govatsmark

Department of Chemical Engineering, NTNU

Outline

- Gas power plant
- Plantwide control
- Plantwide control procedure
- Application
- Concluding remarks

Gas power plant



Plantwide Control

Structural decisions of the control system for an overall plant

Important questions:

1 Which variable to control

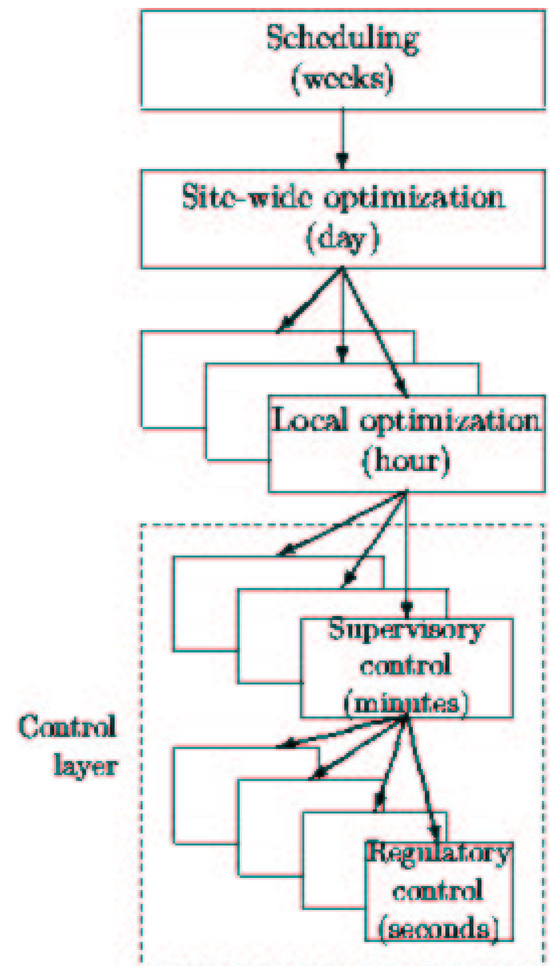
2 Which variable to manipulate

3 Which control configuration

4 Which controller type

Difficult:

Integrated processes



Plantwide Control Procedure (Larsson and Skogestad,2000)

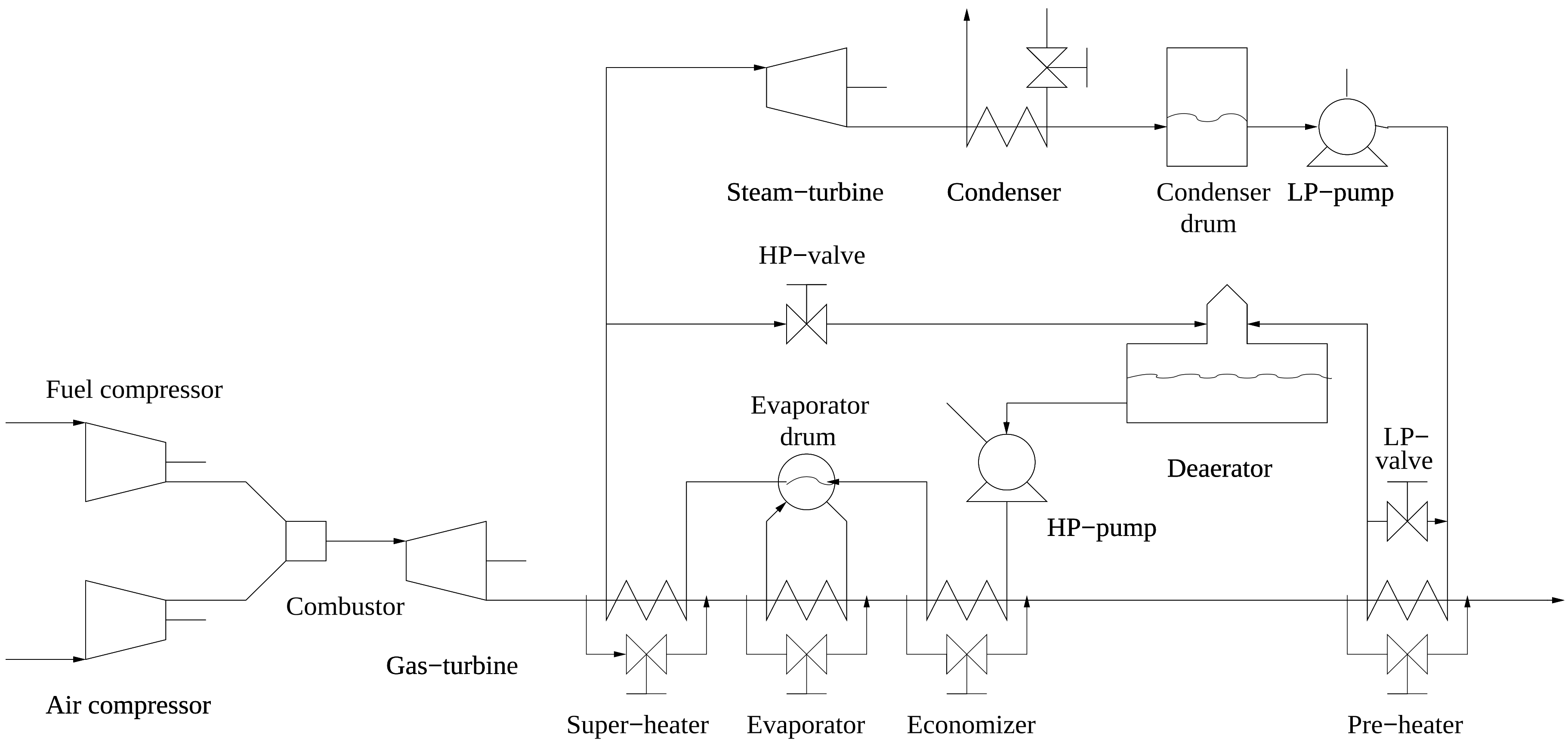
I. Top down analysis

1. Manipulated variables
2. Degree of freedom analysis
3. Primary controlled variables (steady-state economics)
4. Production rate manipulator

II. Bottom up design of the control system

5. Structure of regulatory control layer (secondary control variables)
6. Structure of supervisory control layer (MPC applications)
7. Structure of optimization layer

Step 1. Manipulated variables: 13
Step 2. Steady-state degrees of freedom: 8



DOF: 13-2(levels without steady-state effect)-1(deaerator pressure)-2(turbine speeds)=8

Step 3. Primary controlled variables

3.1 Degrees of freedom for optimization

3.2 Define optimal operation (cost and constraints)

3.3 Identification of important disturbances

3.4 Optimization

3.5 Identification of candidate controlled variables

3.6 Evaluation of loss

3.1 Degrees of freedom for optimization: 8

3.2 Define optimal operation

Maximize profite

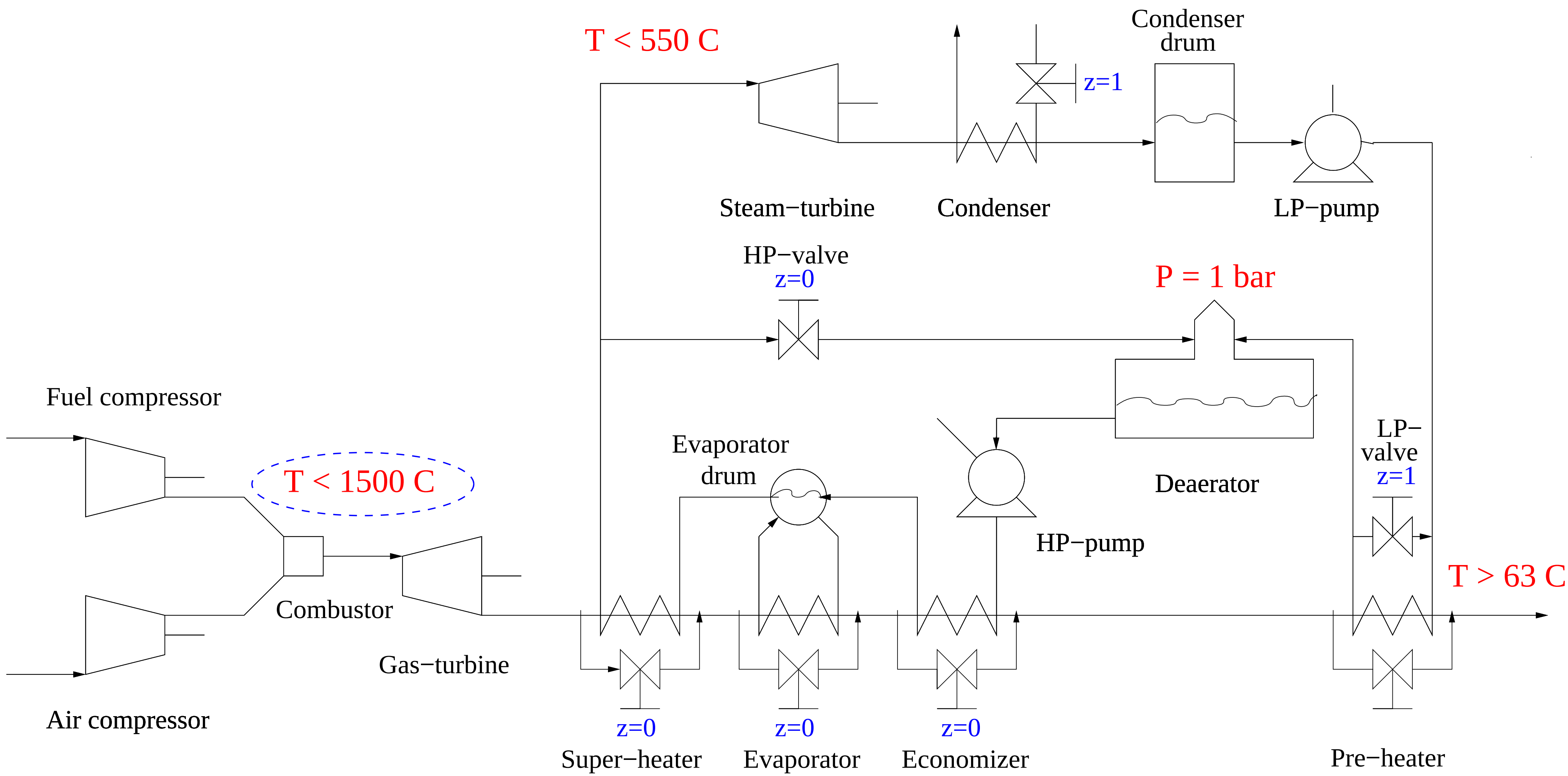
$$-J = 0.1 W_{net} - F_{fuel}$$

Constraints:

$T_{combustor}$	≤ 1500 C	active
$T_{g,super,in}$	≤ 550 C	
$T_{w,pre,in}$	≥ 63 C	
$F_{LPvalve}$	$\leq F_{LPvalve,max}$	active
F_{cw}	$\leq F_{cw,max}$	active
$Flows$	≥ 0	4 active

3.3 Disturbances: $d = T_{air} = 20 \pm 10^o C$

3.4 Optimization: 7 optimal active constraints



T < 550 C
Condenser
drum
z=1
Steam−turbine
Condenser
LP−pump
HP−valve
z=0
P = 1 bar
Fuel compressor
T < 1500 C
Evaporator
drum
Deaerator
LP−
valve
z=1
HP−pump
T > 63 C
Combustor
Gas−turbine
Air compressor
z=0
Super−heater
z=0
Evaporator
z=0
Economizer
Pre−heater

Step 3.5: Identify candidate controlled variables

Use active constraint control ⇒ 8-7= 1 unconstrained variable

Candidates	Implementation error
Flowrates	±10%
Pressures	±2.5%
Temperatures	$\pm 1^{o}$C
Flowratios	±20%
Work	±30%
Duty	±30%
Compressor speed	10%
Combustor temperature	$\pm 10^{o}$C

Which variable should be controlled?

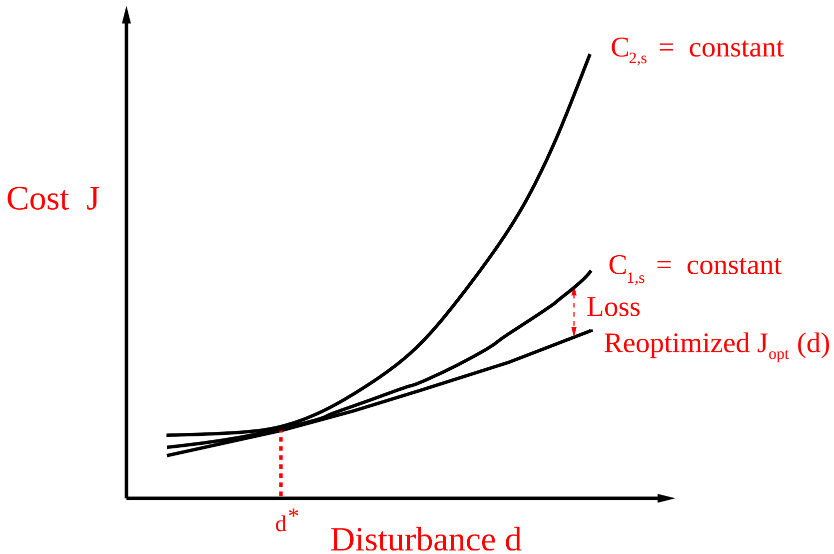
Screening of candidate controlled variables

Maximize steady-state gain ($|G(0)|$)

Rank	c_8	$\|G(0)\|$
1	$T_{g,super,in}$	7.6936
2	$P_{combustor}$	3.6352
3	F_{air}	2.3358
4	F_{fuel}	0.9587
5	F_{fuel}/F_{air}	0.6211
6	$T_{w,pre,in}$	0.1102

Step 3.6 Loss evaluation with nominal setpoints

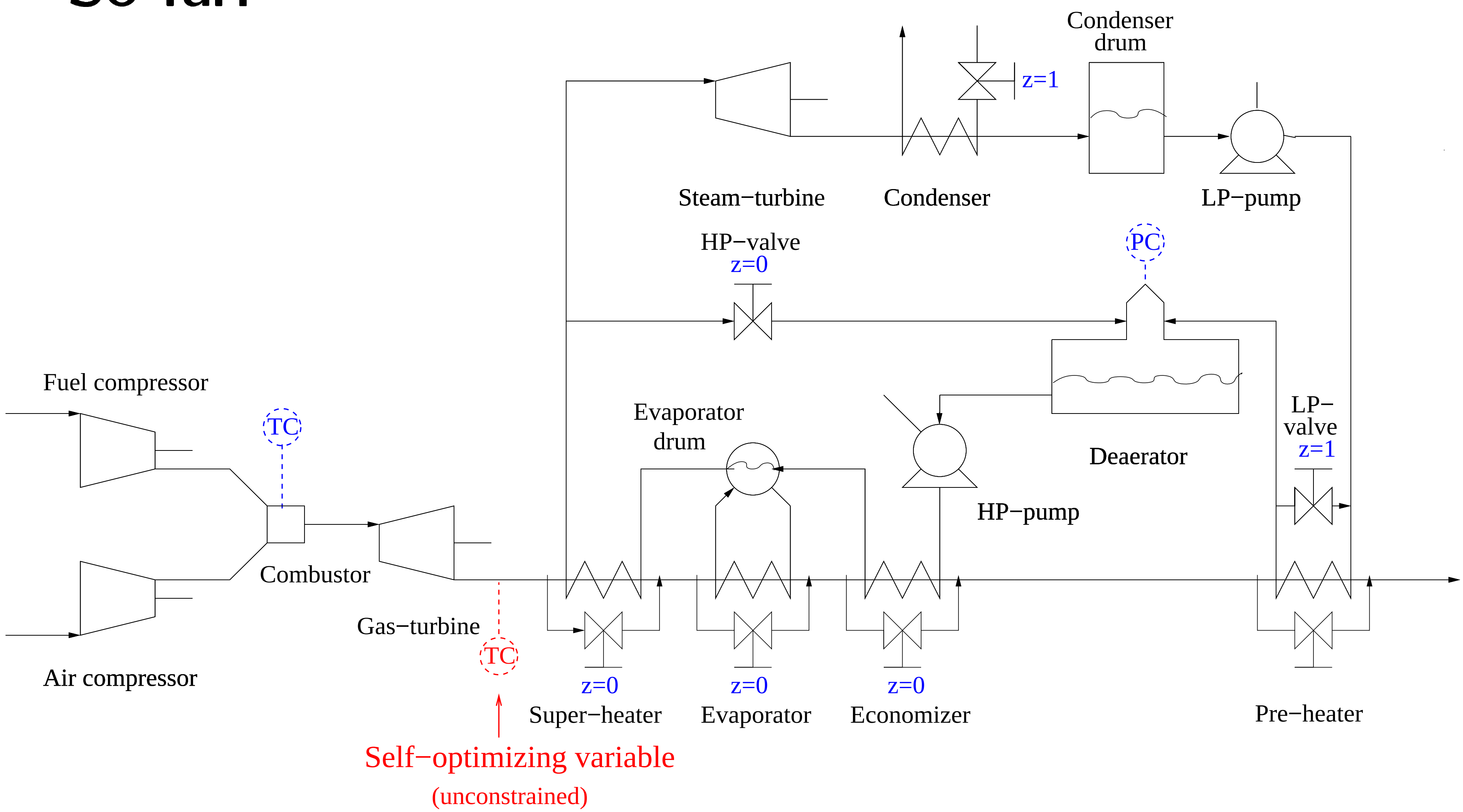
Rank	Alt./$c_{s,8}$	Average loss
–	On-line opt.	2.40%
1	$T_{g,super,in}$	2.56%
2	$P_{combustor}$	2.60%
3	F_{air}	3.21%
–	F_{fuel}	Infeasible
–	F_{fuel}/F_{air}	Infeasible
–	$T_{w,pre,in}$	Infeasible



Step 4. Production rate manipulator

Not relevant for gas phase system

So far:



Condenser drum
z=1
Steam−turbine
Condenser
LP−pump
HP−valve
z=0
PC
Fuel compressor
TC
Evaporator drum
LP− valve
z=1
Deaerator
HP−pump
Combustor
Gas−turbine
TC
Air compressor
z=0
z=0
z=0
Super−heater
Evaporator
Economizer
Pre−heater
Self−optimizing variable
(unconstrained)

II: Bottom-up design of control system
Step 5. Structure of regulatory control layer

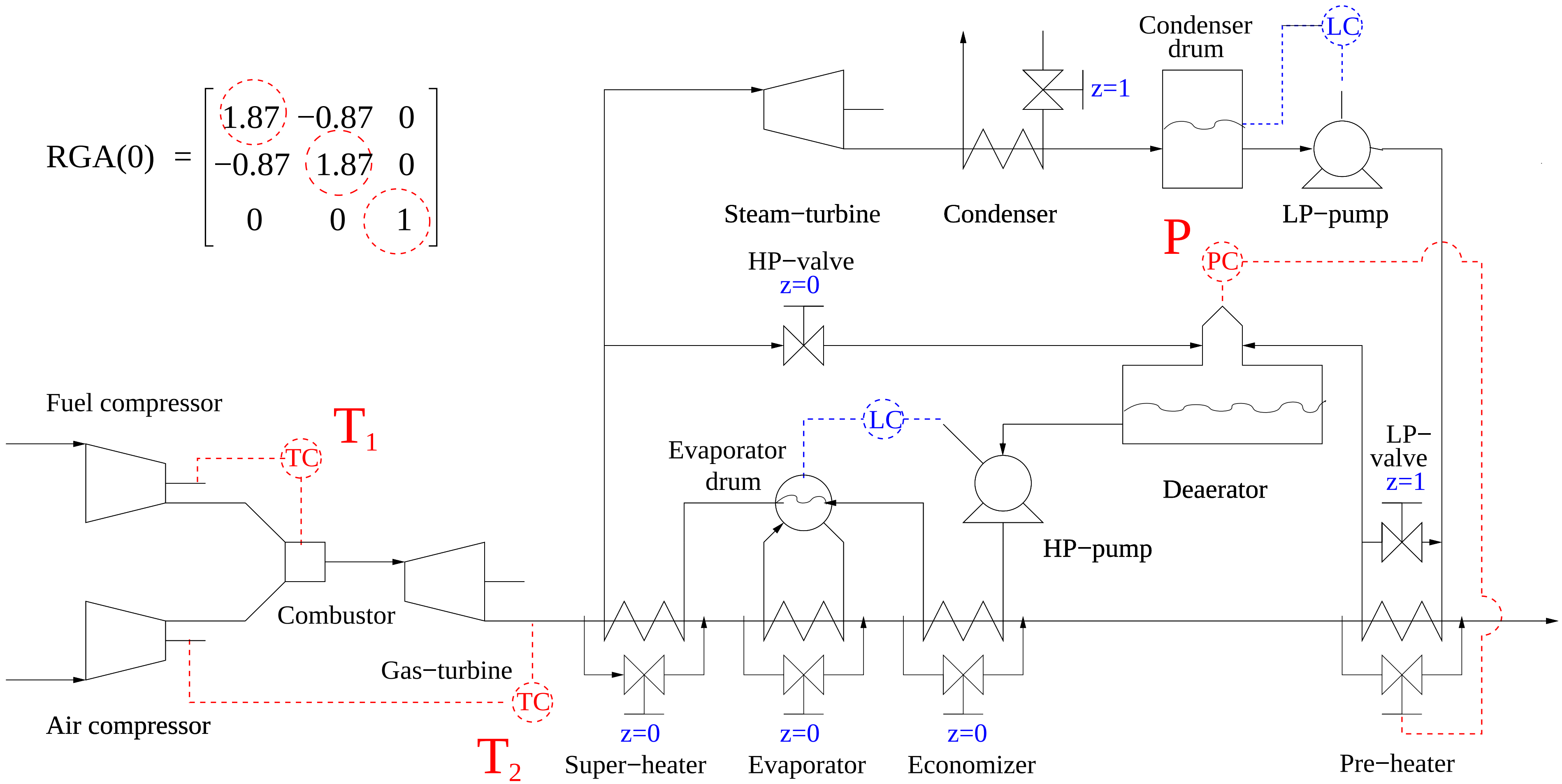
Stabilization:
Evaporator drum level $\leftrightarrow$ LP-pump flowrate
Condenser drum level $\leftrightarrow$ HP-pump flowrate

Local disturbance rejection: Use local flow controller

Step 6. Structure of supervisory control layer

Proposed decentralized control structure

$$\mathrm{RGA}(0) = \begin{bmatrix} 1.87 & -0.87 & 0 \\ -0.87 & 1.87 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

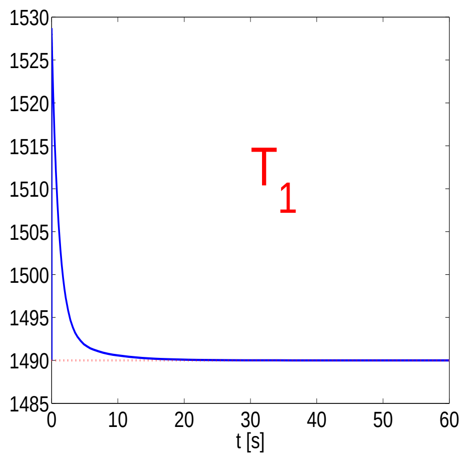


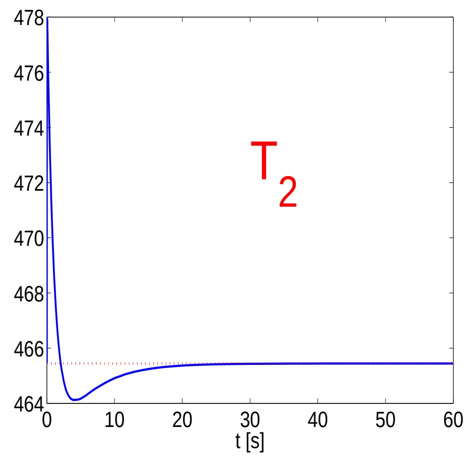
Step 7. Structure of optimization layer

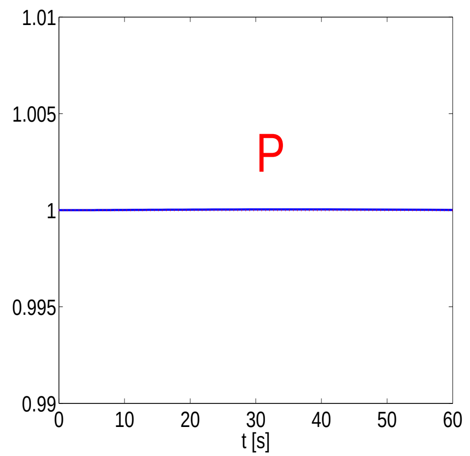
On-line optimization is not needed.

Loss:
Super-heater inlet temperature : 2.56%
On-line optimization : 2.40%

Validation by simulation: $\Delta T_{air} = +10^o C$





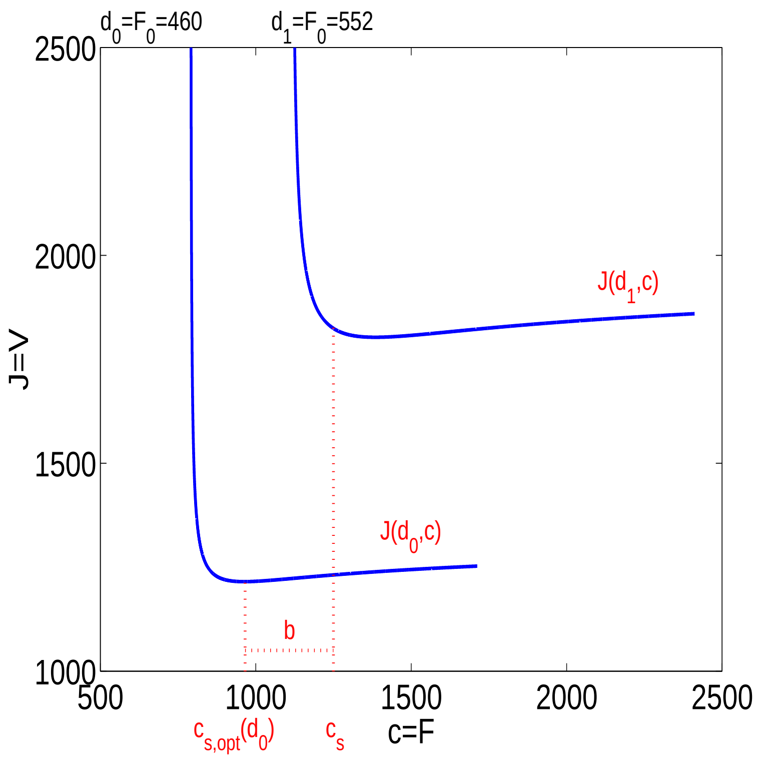


Concluding remarks

- Demonstrated a systematic procedure for selection of plantwide control structure on a simple gas power plant.

- Control: Super-heater gas inlet temperature
  $\Rightarrow$ simple system + close to optimal operation

Step 3.6 Optimal back-off by robust optimization off-line (Glemmestad et.al.,1998)



Robust optimization:

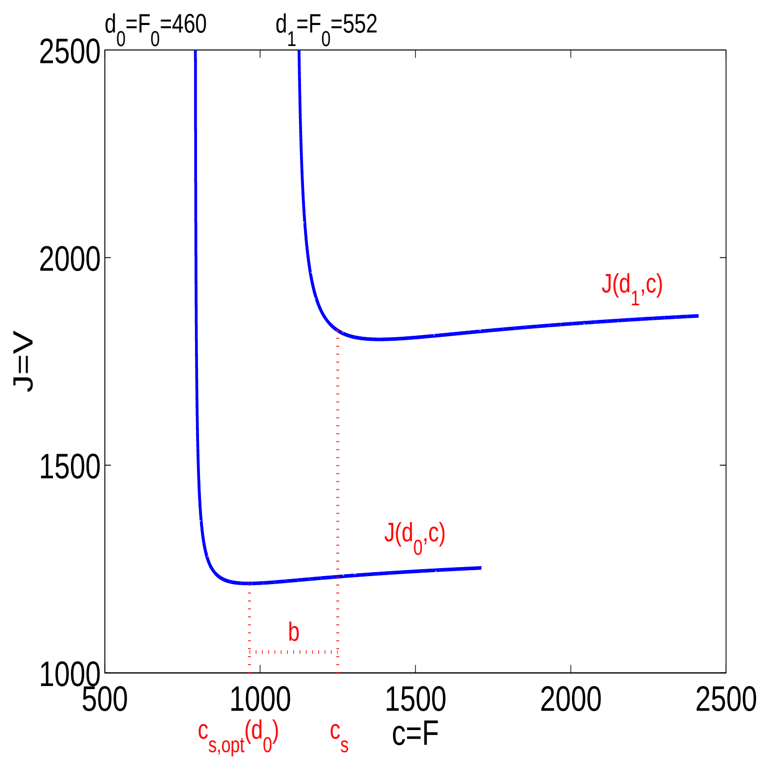
$$
\begin{aligned}
\min_{x_i,u_i,c_s} \sum_i w_i J(x_i,u_i,d_i) & \\
f(x_i,u_i,d_i) &= 0 \\
g(x_i,u_i,d_i) &\leq 0 \\
c(x_i,u_i,d_i) &= c_s + n_i \\
d_i &\in D \\
e_i &\in E
\end{aligned}
$$

"Optimal back-off":

$$b_{opt} = c_{s,robust} - c_{s,opt}(d_0)$$

F_{fuel}: Loss=9.44%, b_8=−2.60

Step 3.6 Flexible back-off from nominal setpoints online (Lid et.al.,2001)



$$\min_{x,u,c_{s,flex}} \ (c_s - c_{s,flex})Q(c_s - c_{s,flex})$$

$$\begin{aligned} f(x,u,d) &= 0 \\ g(x,u,d) &\leq 0 \\ c(x,u,d) &= c_{s,flex} + n \\ c_s &= c_{s,opt}(d_0) \\ d &\in D \\ e &\in E \end{aligned}$$

"Flexible back-off":

$$b_{flex} = c_{s,flex}(d) - c_{s,opt}(d_0)$$

F_{fuel}: Loss=9.23%, b_8=[−5.1, 0]