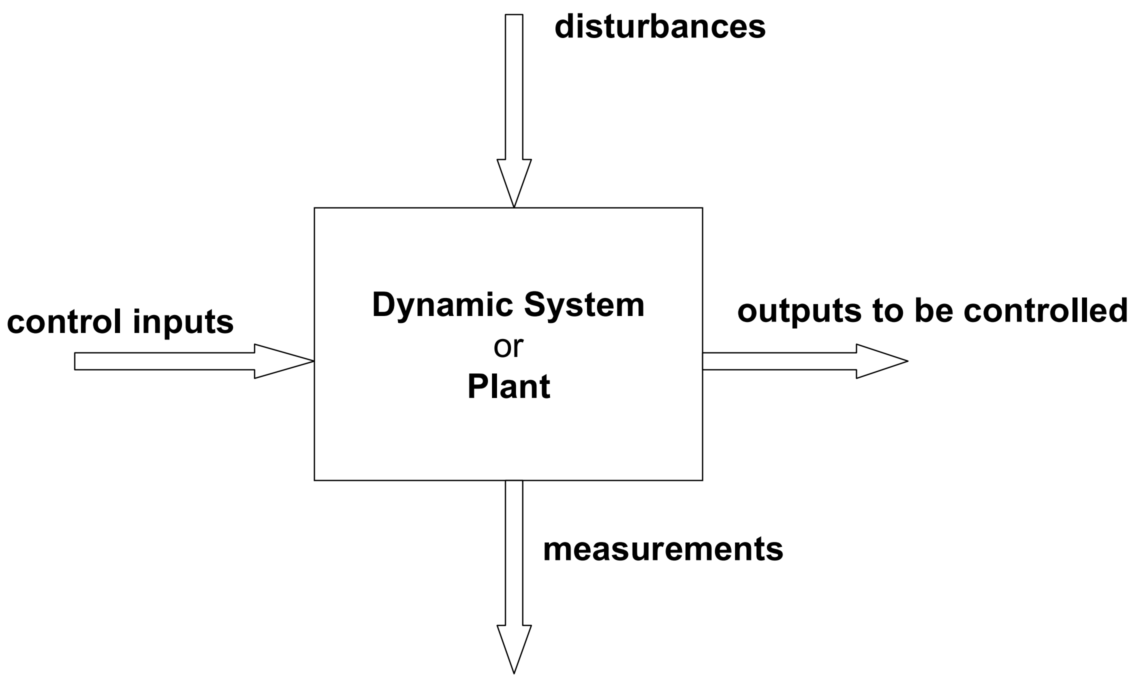
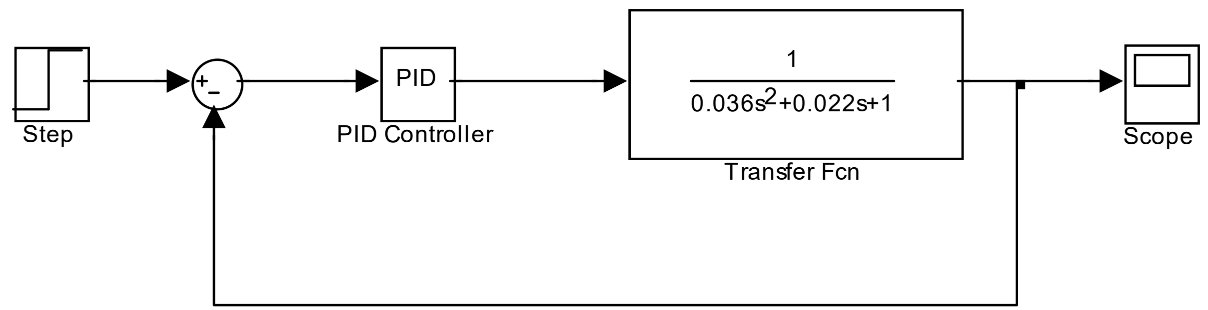
Power Plant Dynamics & Control

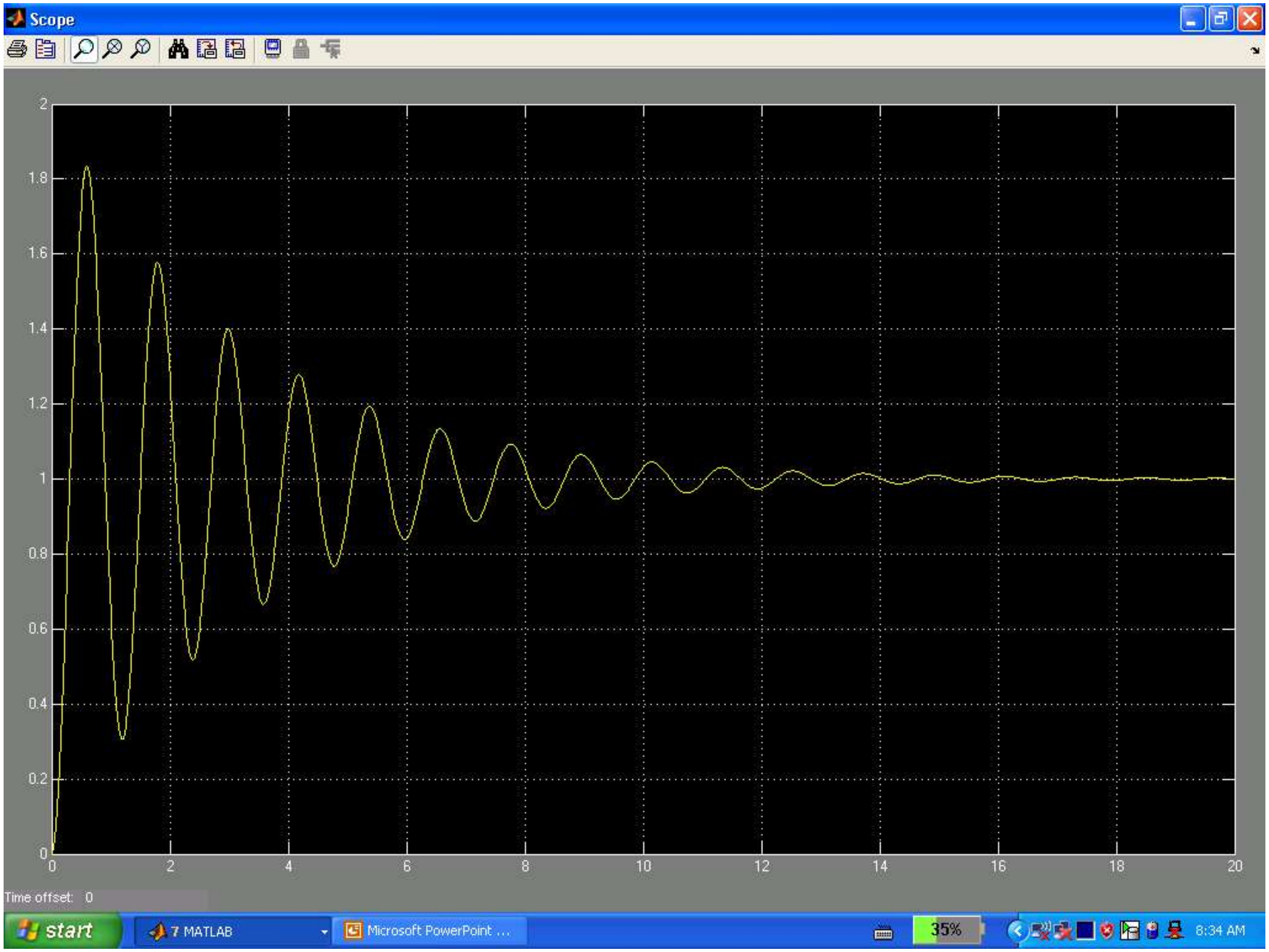
Prof. Dr. Amitava Gupta

A plant in general



A typical control loop and its dynamics

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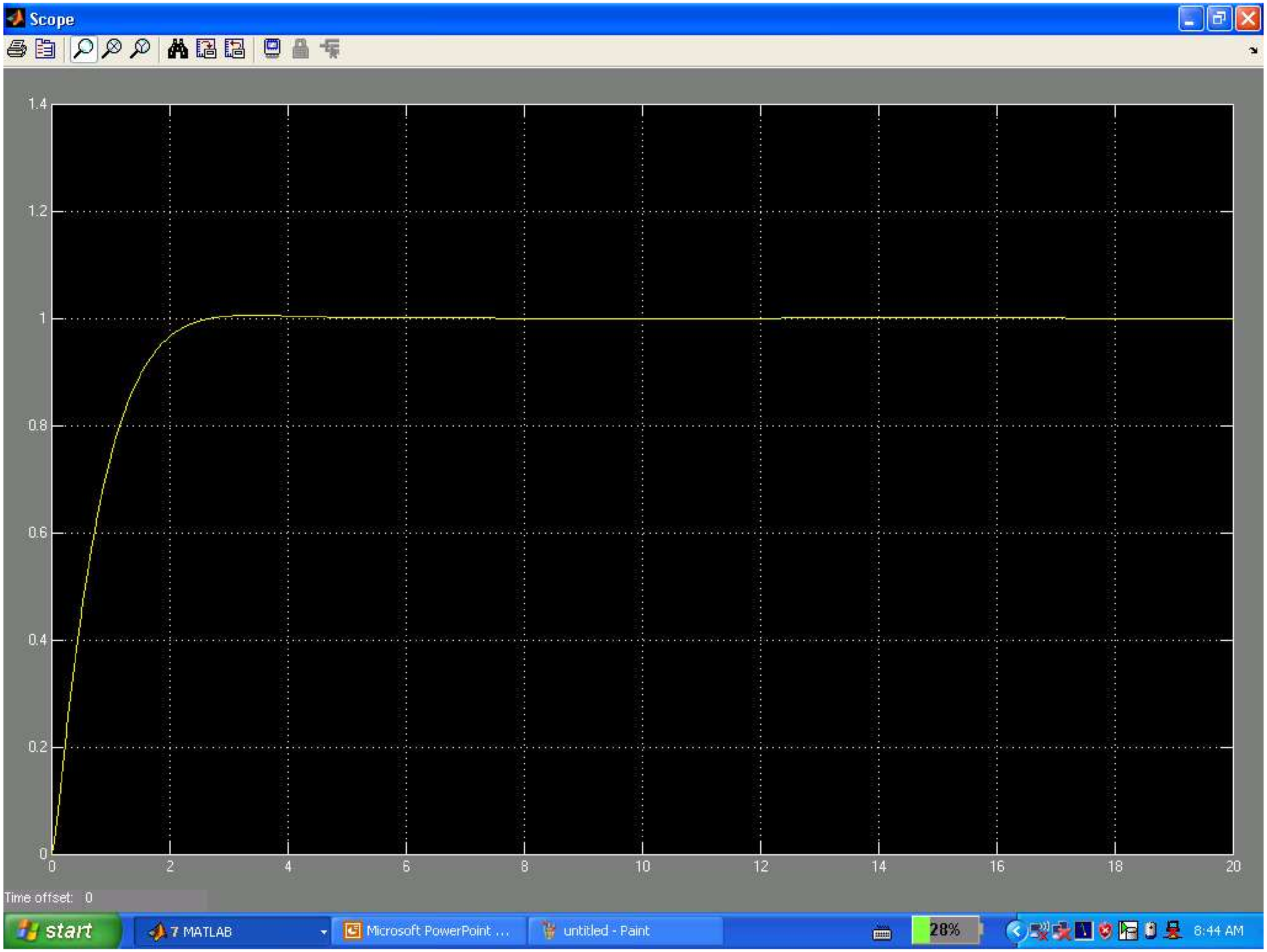
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
18
20
Time offset: 0
start
7 MATLAB
Microsoft PowerPoint ...
35%
8:34 AM


Scope
1.4
1.2
1
0.8
0.6
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0.2
0
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4
6
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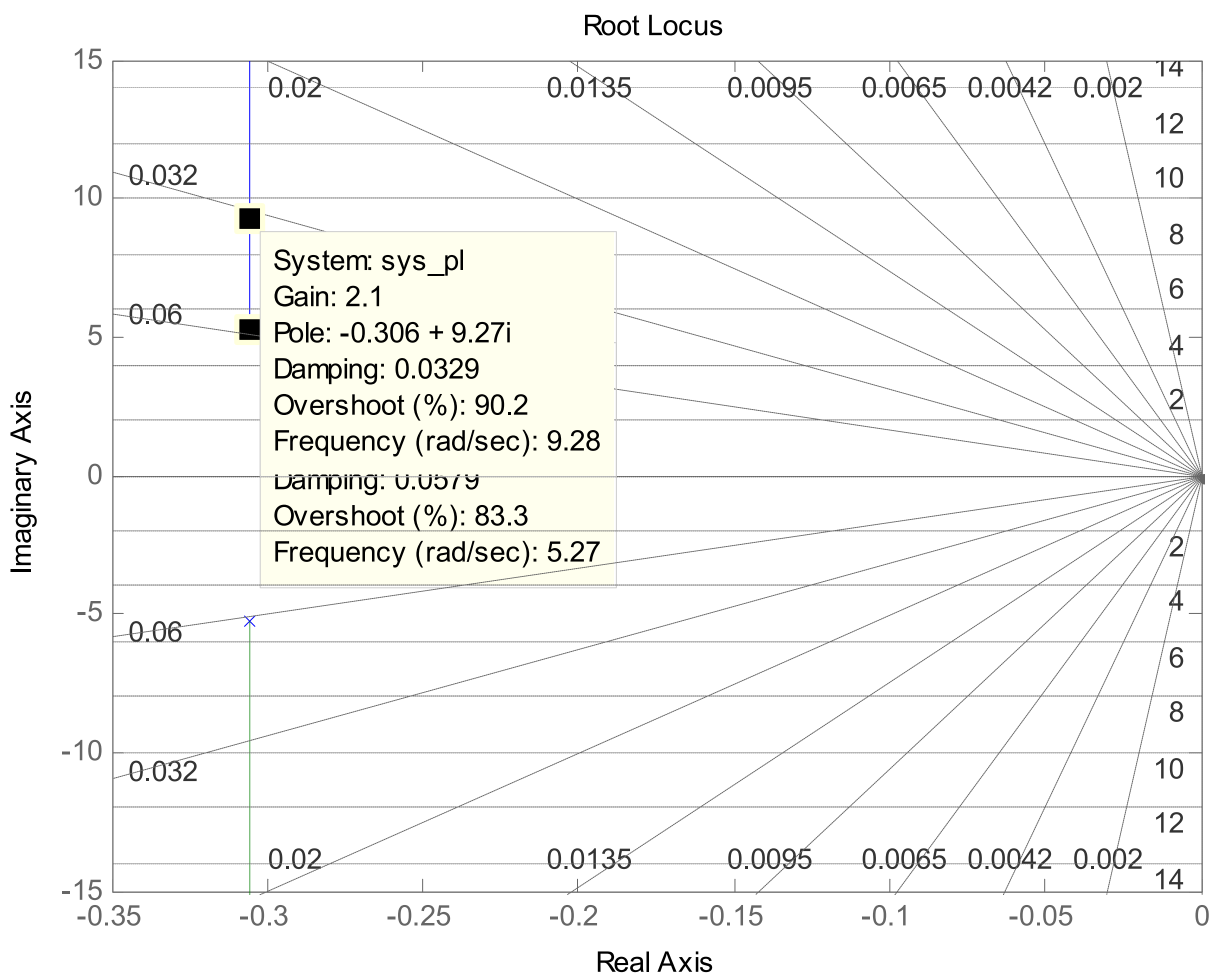
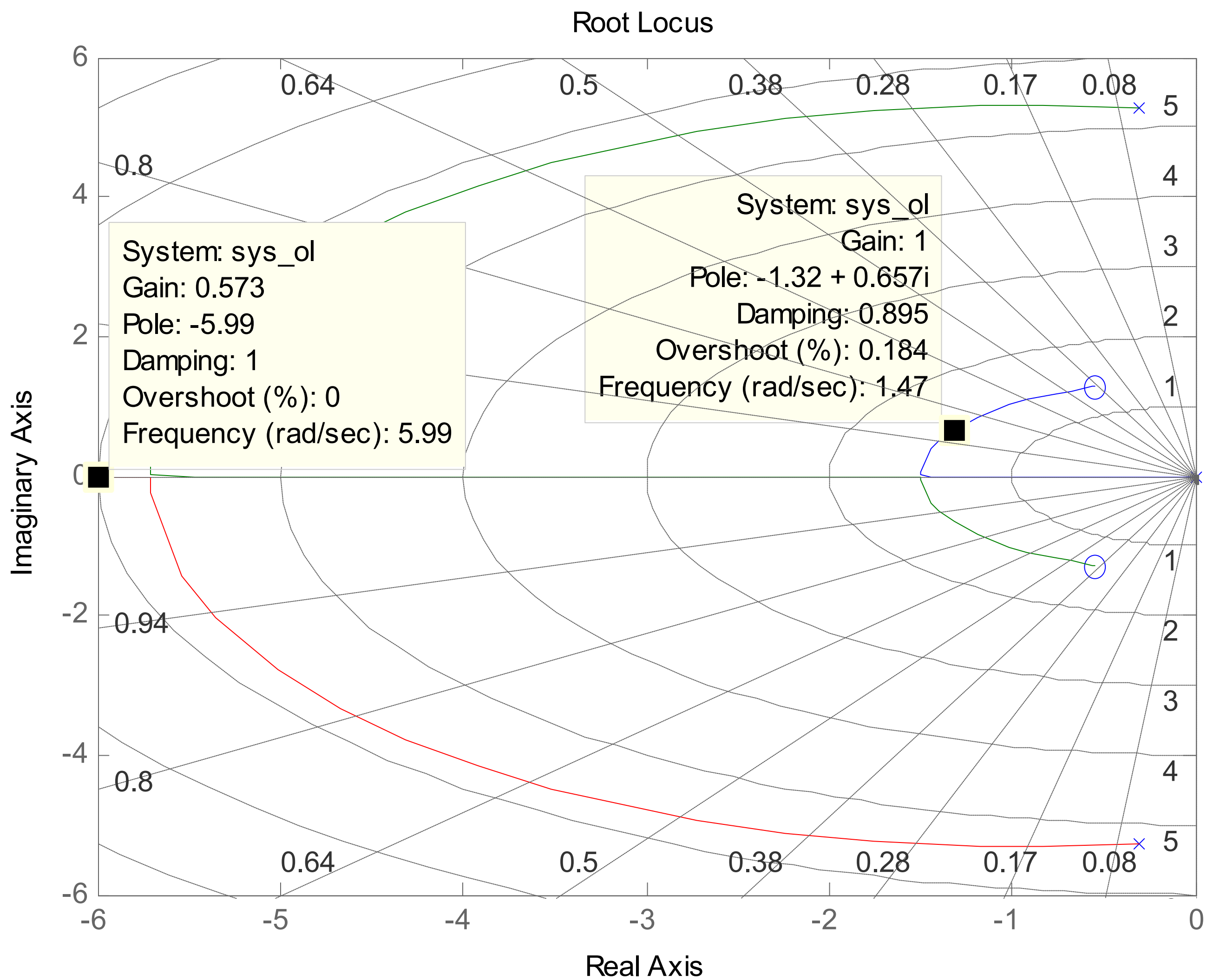
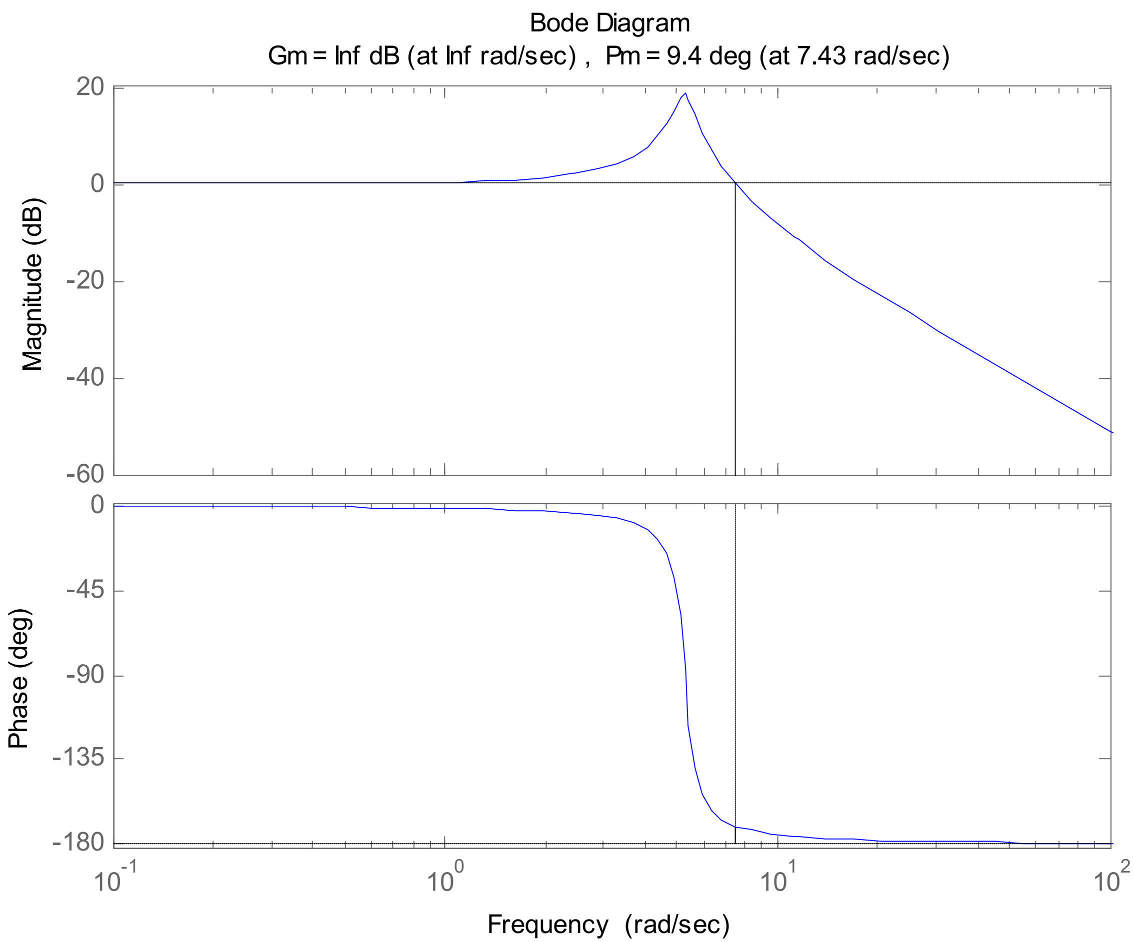
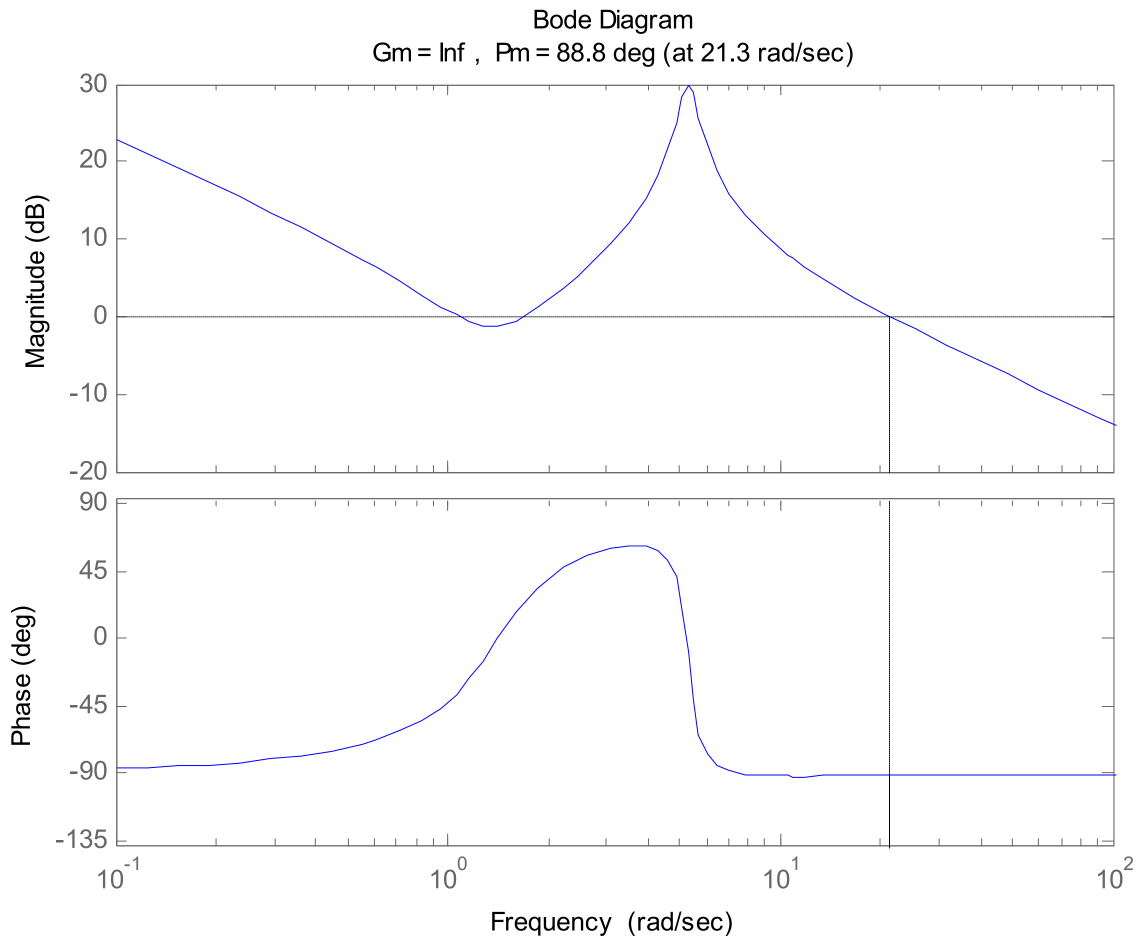
16
18
20
Time offset: 0


Root Locus
System: sys_pl
Gain: 2.1
Pole: -0.306 + 9.27i
Damping: 0.0329
Overshoot (%): 90.2
Frequency (rad/sec): 9.28
Damping: 0.0579
Overshoot (%): 83.3
Frequency (rad/sec): 5.27
0.02
0.0135
0.0095
0.0065
0.0042
0.002
0.032
0.06
Imaginary Axis
Real Axis


Root Locus
System: sys_ol
Gain: 0.573
Pole: -5.99
Damping: 1
Overshoot (%): 0
Frequency (rad/sec): 5.99
System: sys_ol
Gain: 1
Pole: -1.32 + 0.657i
Damping: 0.895
Overshoot (%): 0.184
Frequency (rad/sec): 1.47
0.64
0.5
0.38
0.28
0.17
0.08
0.8
0.94
Imaginary Axis
Real Axis
-6
-5
-4
-3
-2
-1
0
6
4
2
-2
-4
-6

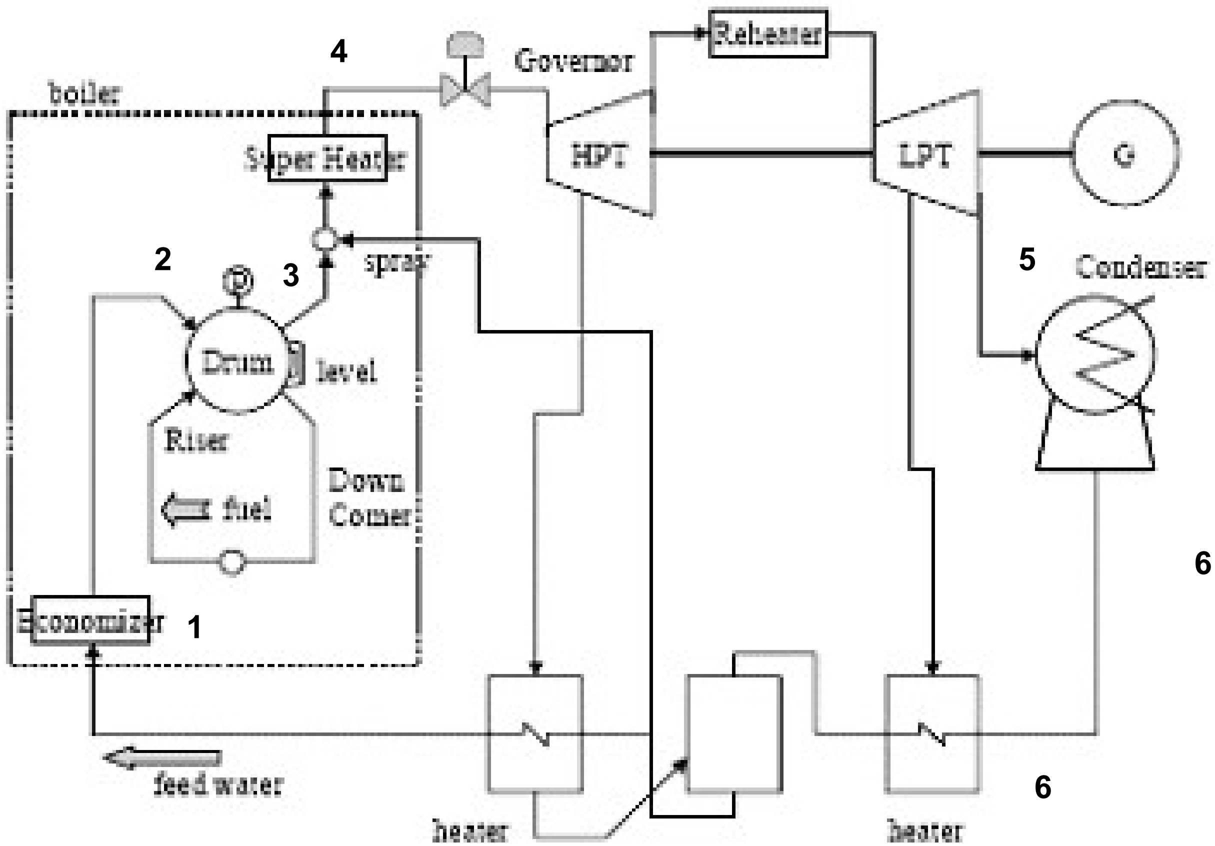

Bode Diagram
Gm = Inf dB (at Inf rad/sec) , Pm = 9.4 deg (at 7.43 rad/sec)
Magnitude (dB)
20
0
-20
-40
-60
Phase (deg)
0
-45
-90
-135
-180
10^-1
10^0
10^1
10^2
Frequency (rad/sec)

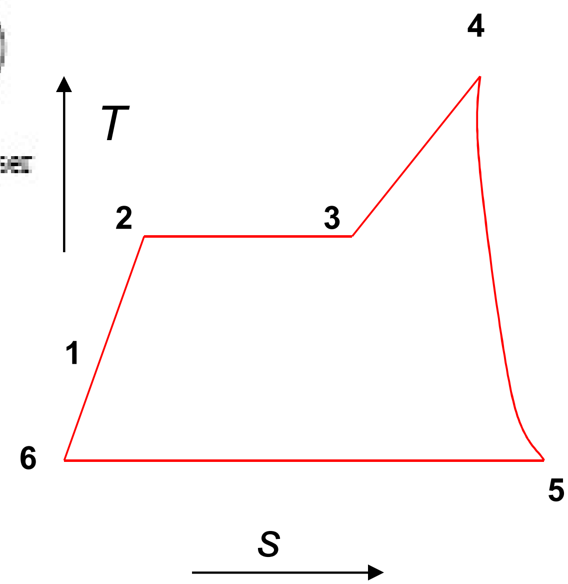

Bode Diagram
Gm = Inf , Pm = 88.8 deg (at 21.3 rad/sec)
Magnitude (dB)
30
20
10
0
-10
-20
Phase (deg)
90
45
0
-45
-90
-135
10^-1
10^0
10^1
10^2
Frequency (rad/sec)

Desirable properties of a controller

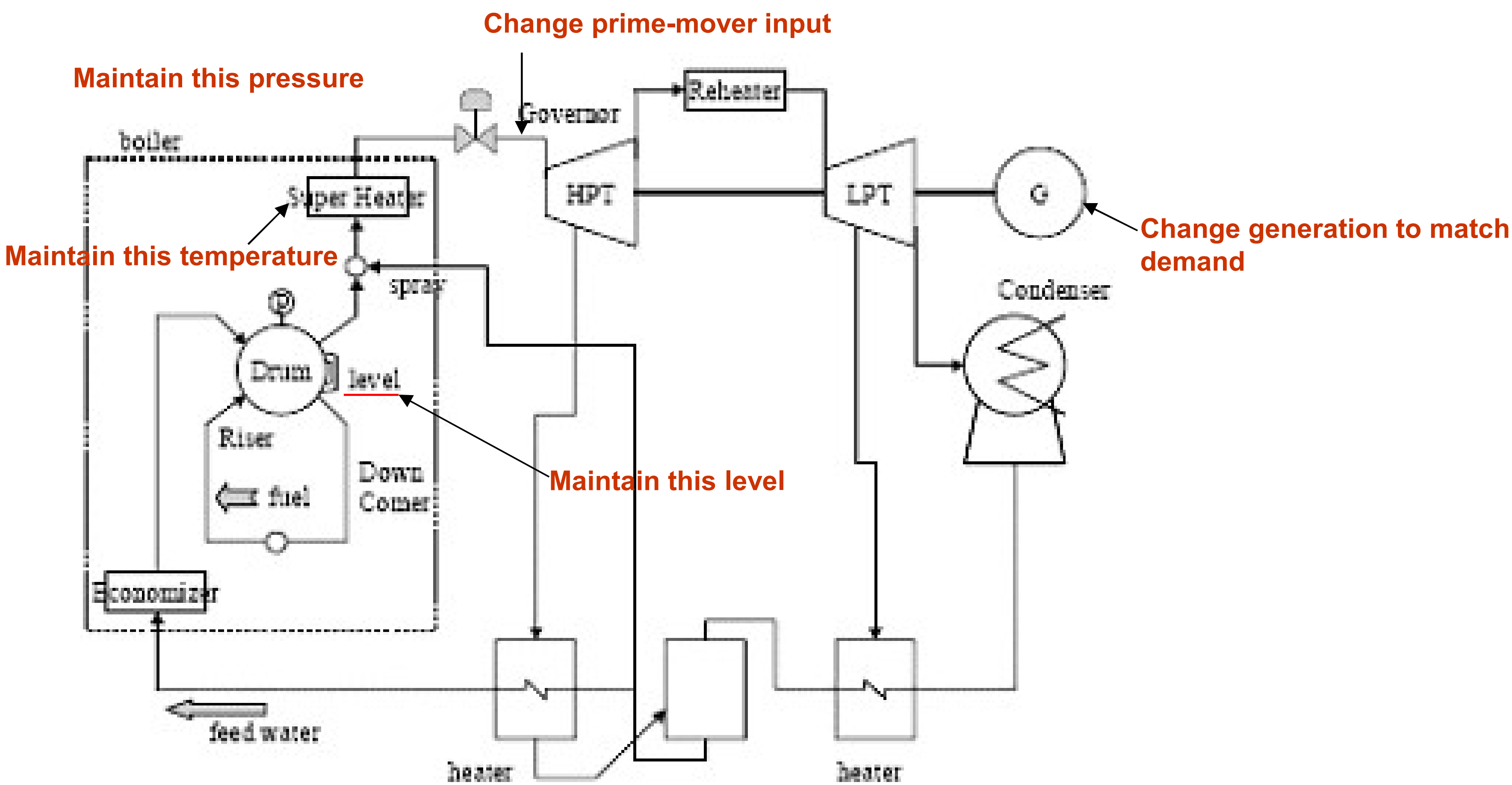
- Should track input (zero steady-state error)
- Should have enough stability robustness: gain and phase margins should be
- comfortable
- Robustness to variations of gain: performance robustness
- Robustness to high frequency noise
- Good output disturbance rejection

Power generation as a process

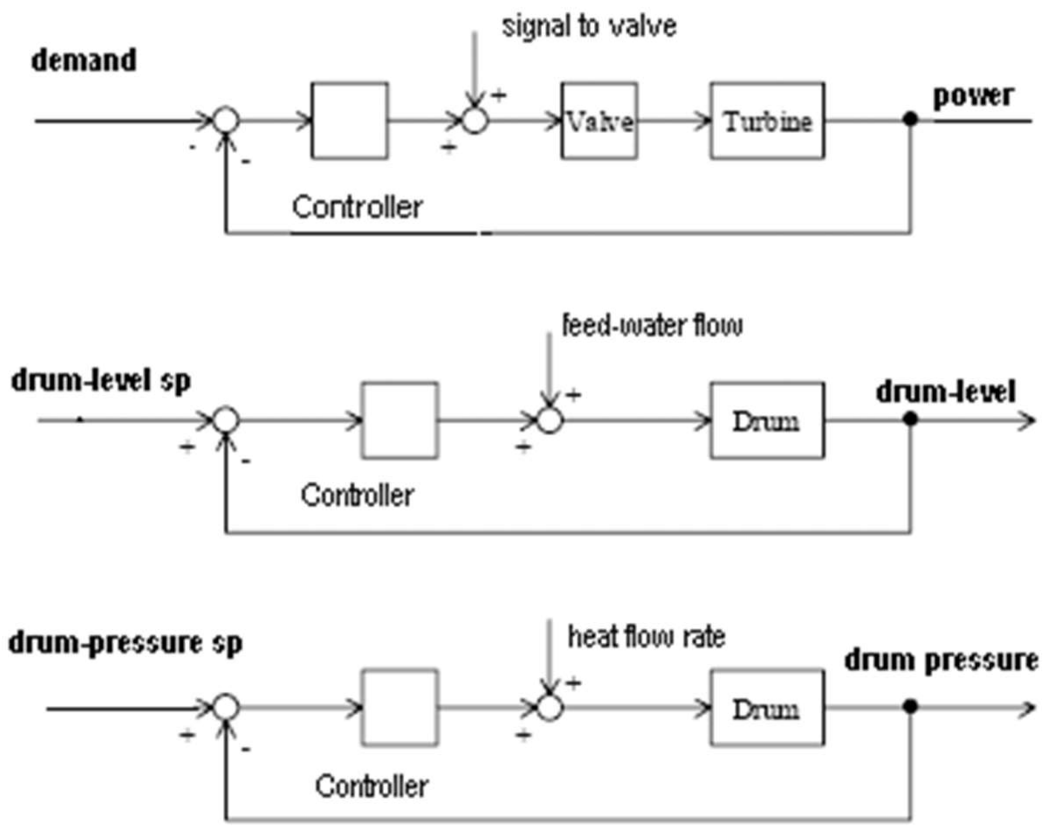




Process control of power generation process



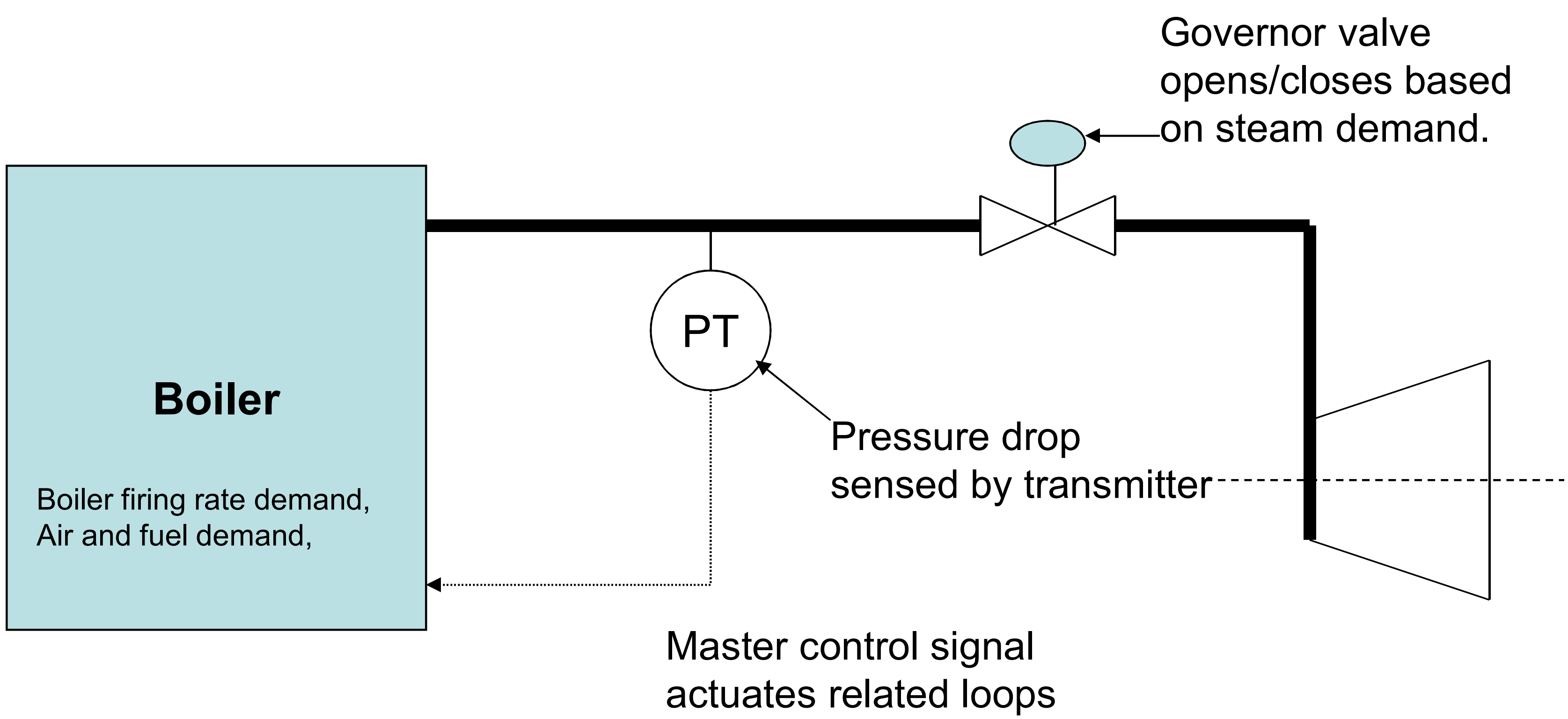
Process control of power generation process: in simplest terms



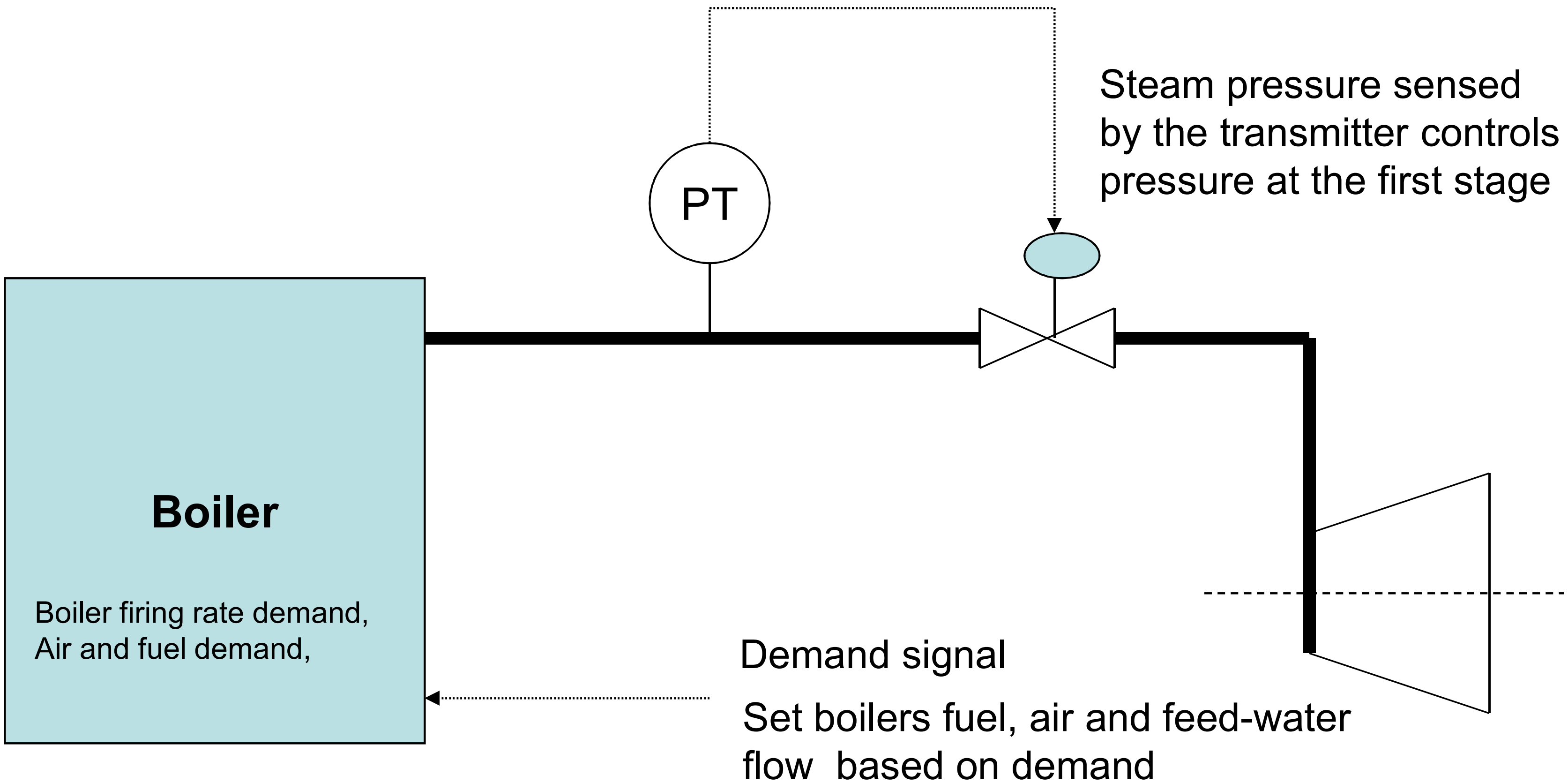
Modulating control loops in a thermal power plant

- Load demand control
- Firing rate control
- Air and fuel flow control
- Secondary air-flow control
- Drum-level control
- Furnace draft control
- Superheater steam temperature control

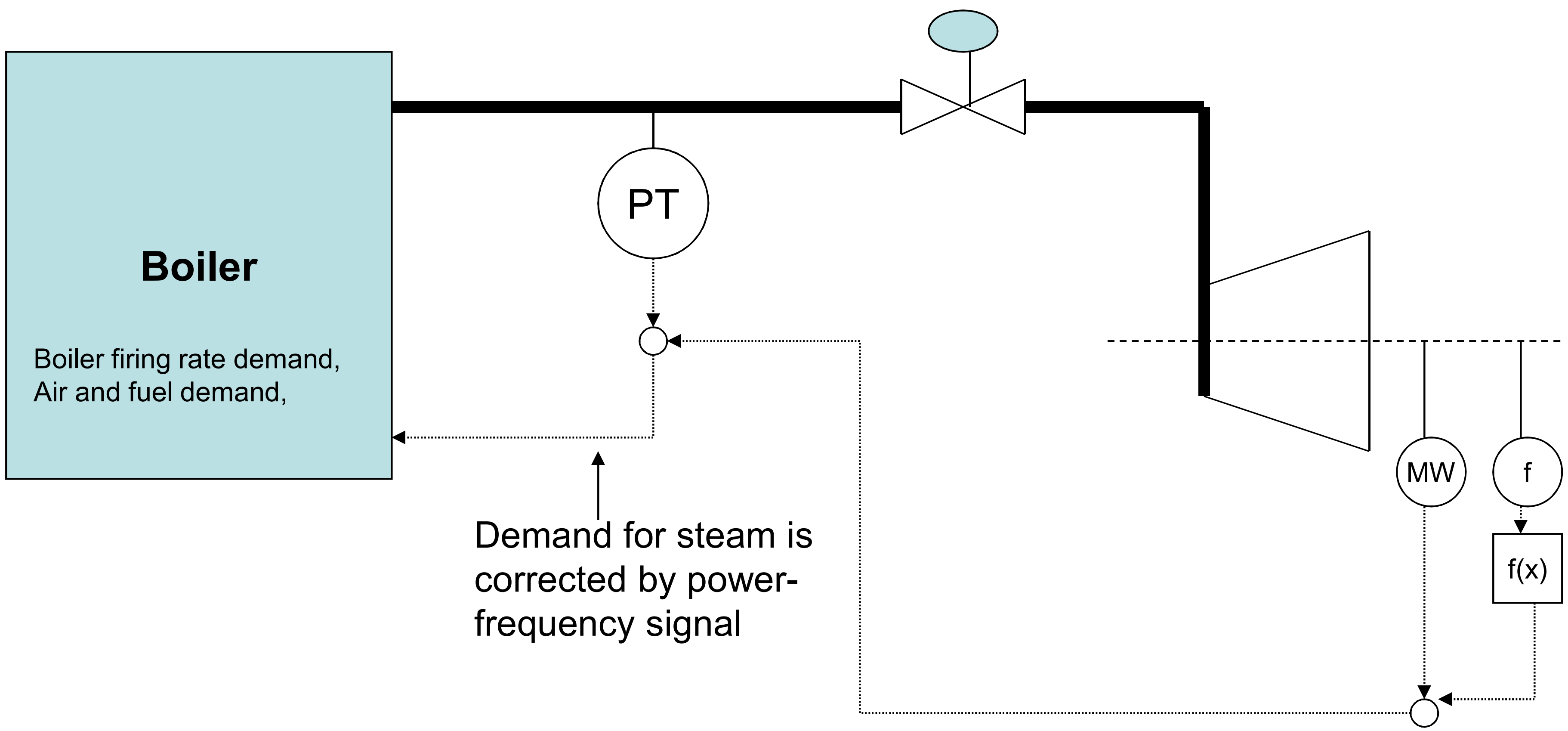
Load demand control: Boiler following turbine



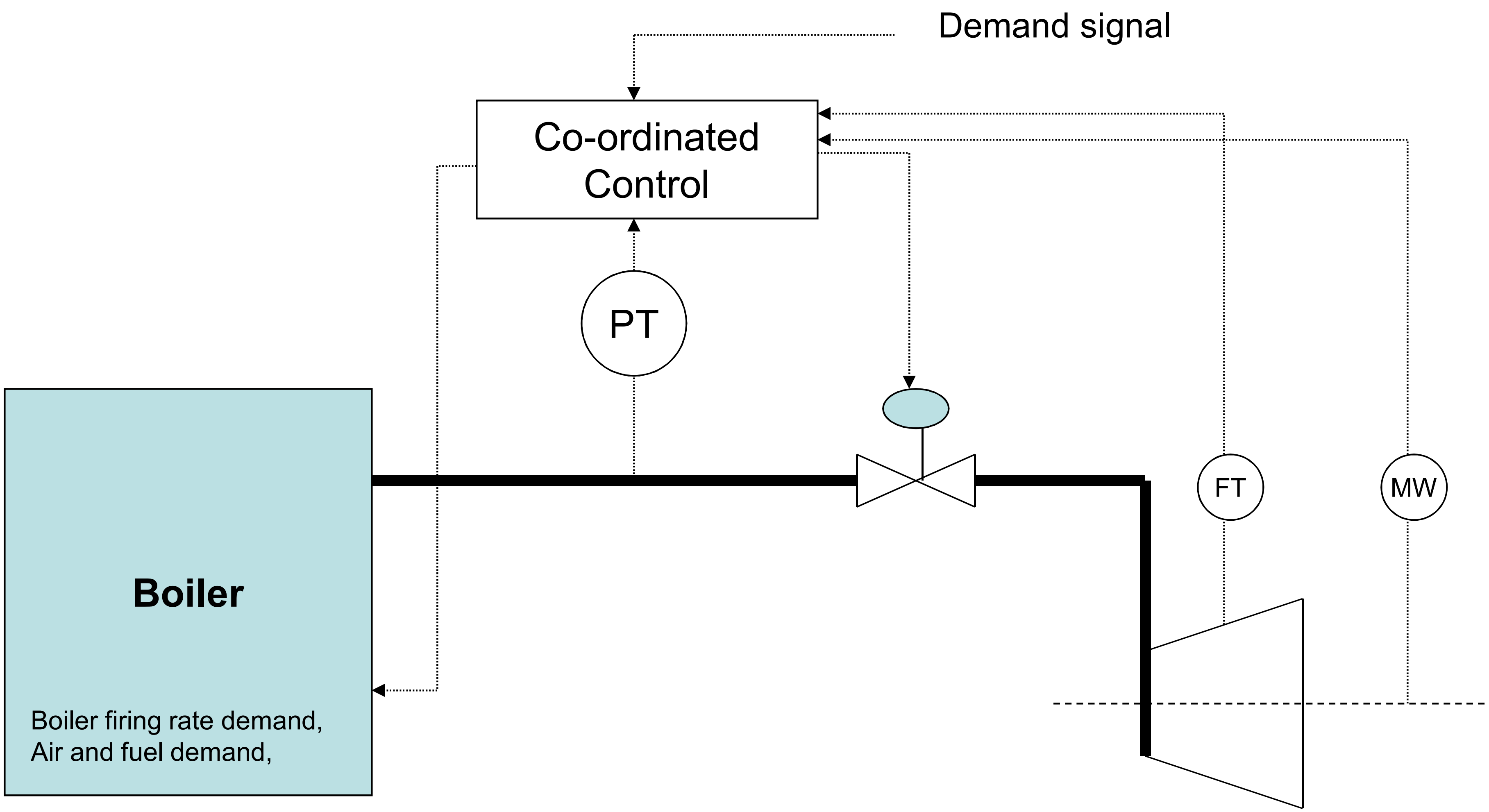
Load demand control: Turbine following boiler



Load demand control: Sliding Pressure mode



Load demand control: Co-ordinated control mode



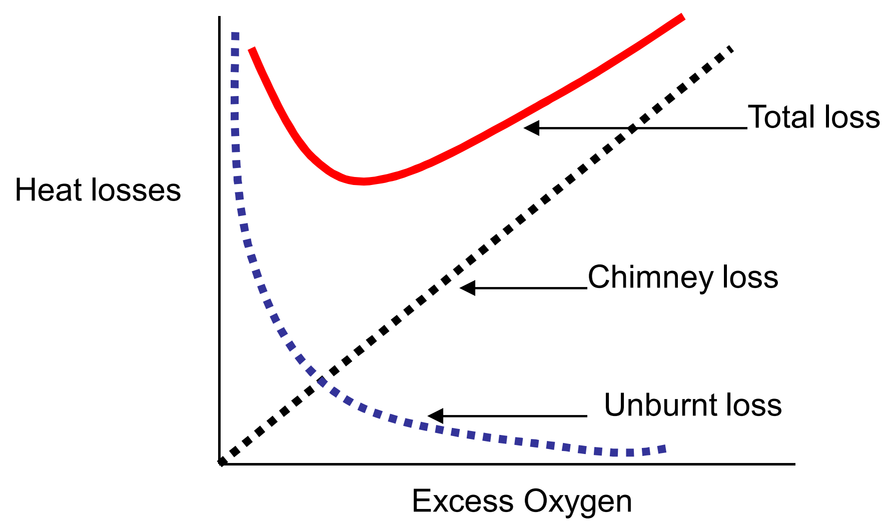
Air and fuel-flow control: Requirements

Control the heat supplied to the boiler by controlling the flow of fuel and air. The ratio of fuel and air is maintained so that incomplete burning due to excess fuel or excessive losses due to excess oxygen do not occur.

Problems due to excess fuel:

Increased pollution
Production of poisonous Carbon Monoxide
Dangerous collection of unburnt fuel in the furnace

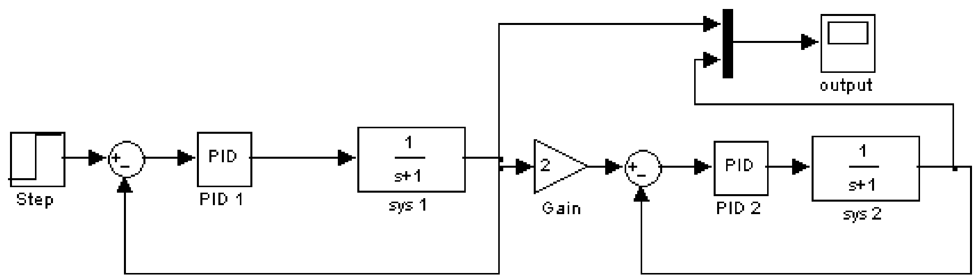
Problems due to excess oxygen:

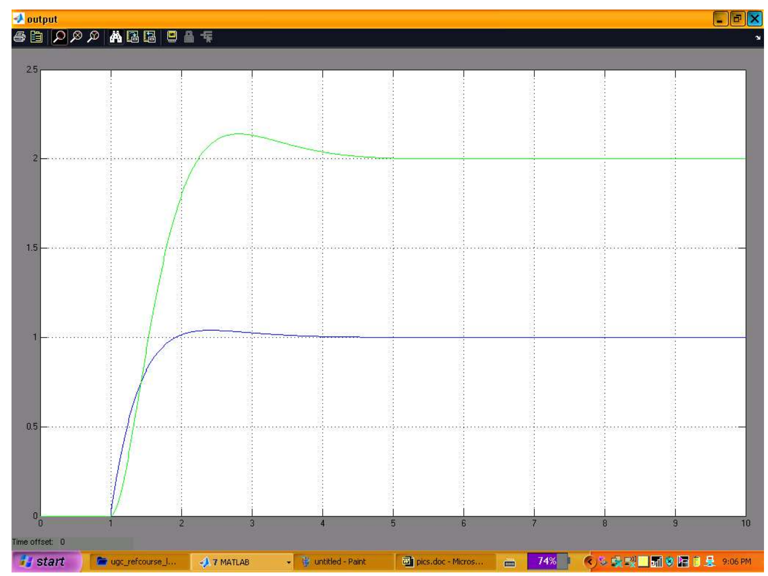


Air and fuel-flow control: Requirements contd..

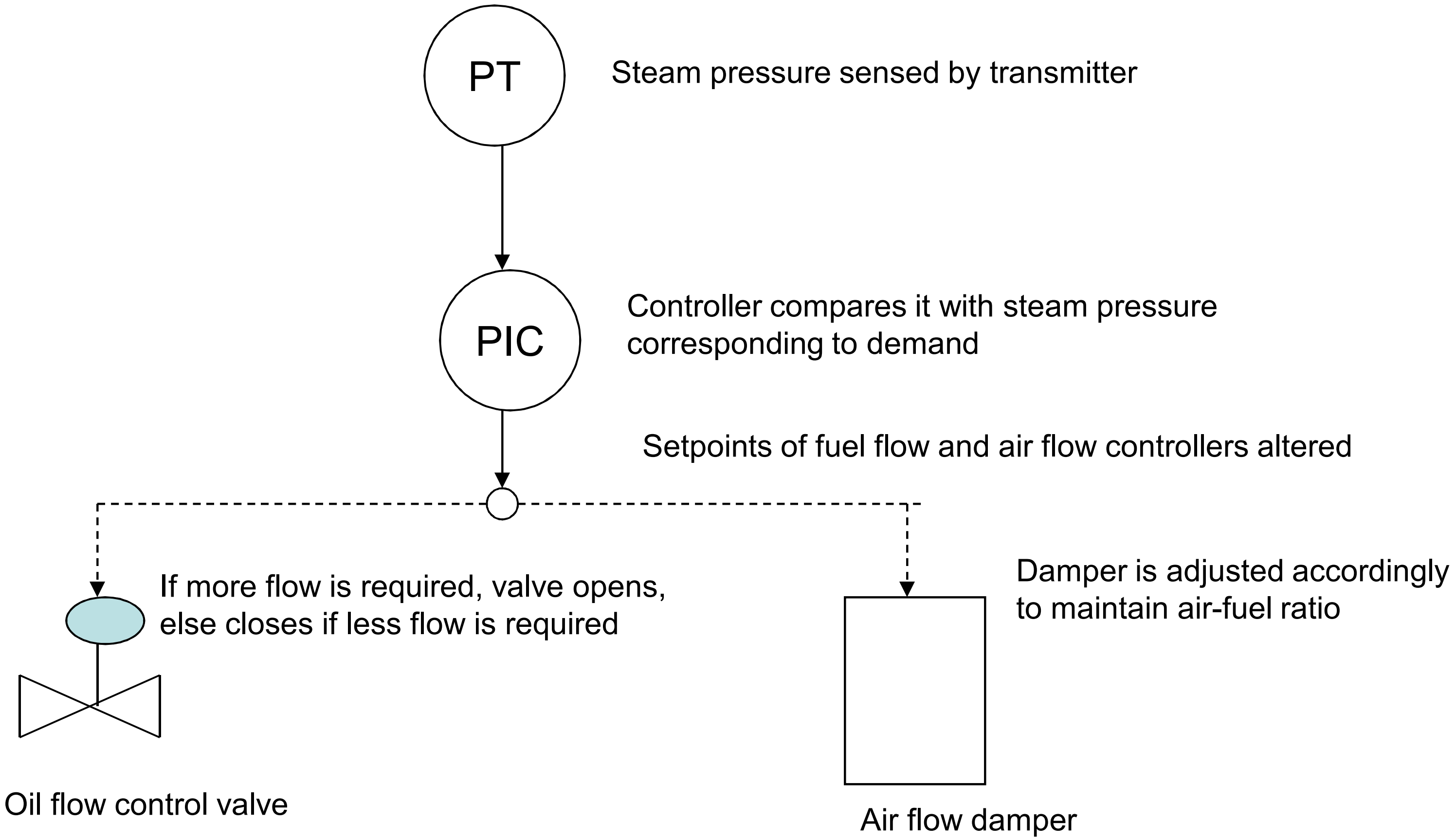
- When demand increases, air-flow must increase first followed by increase in fuel flow.
- When demand decreases, fuel-flow must decrease first followed by decrease in air-flow

Air and fuel-flow control: A ratio controlled loop





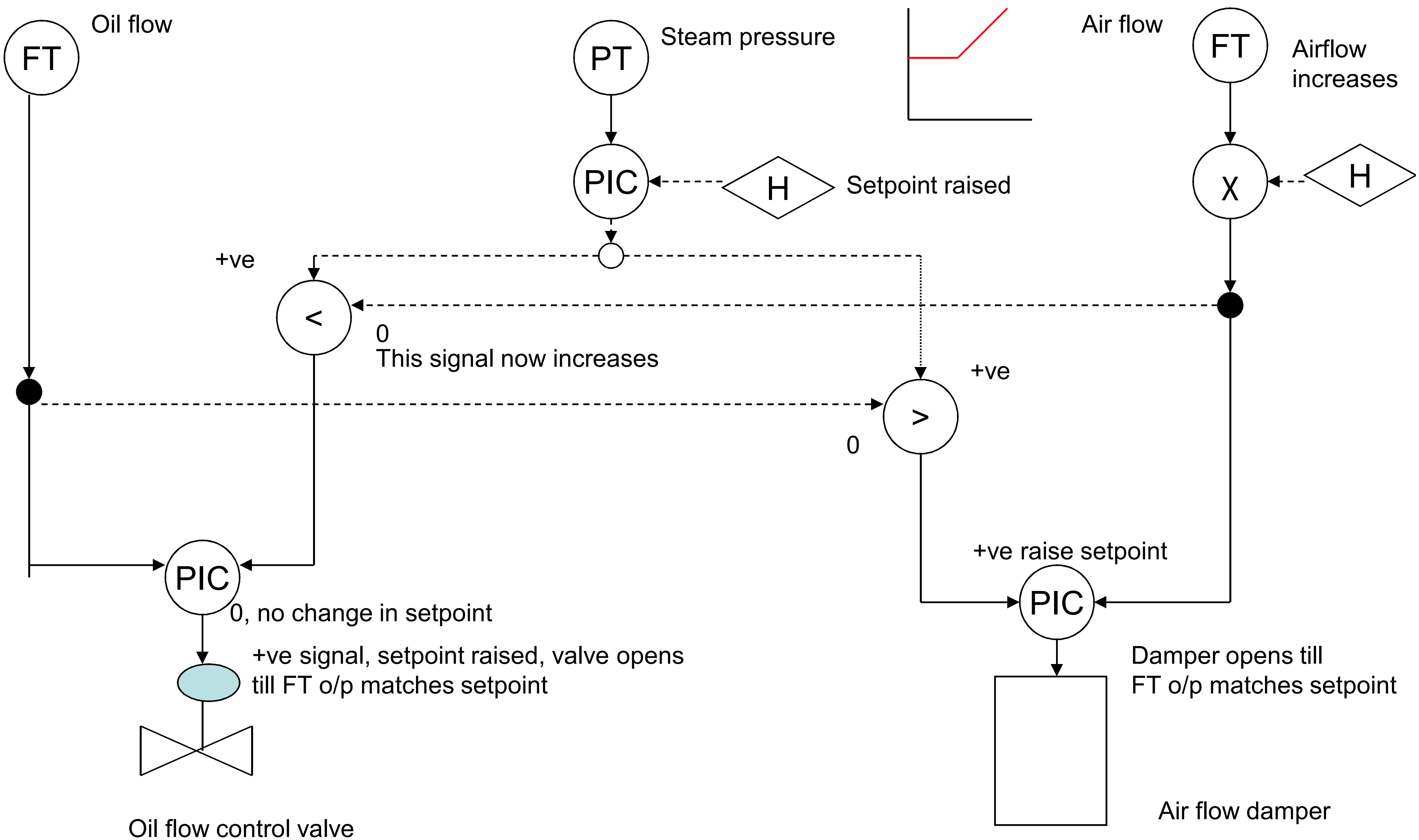
Air and fuel-flow control: A simple scheme for an oil-fired boiler



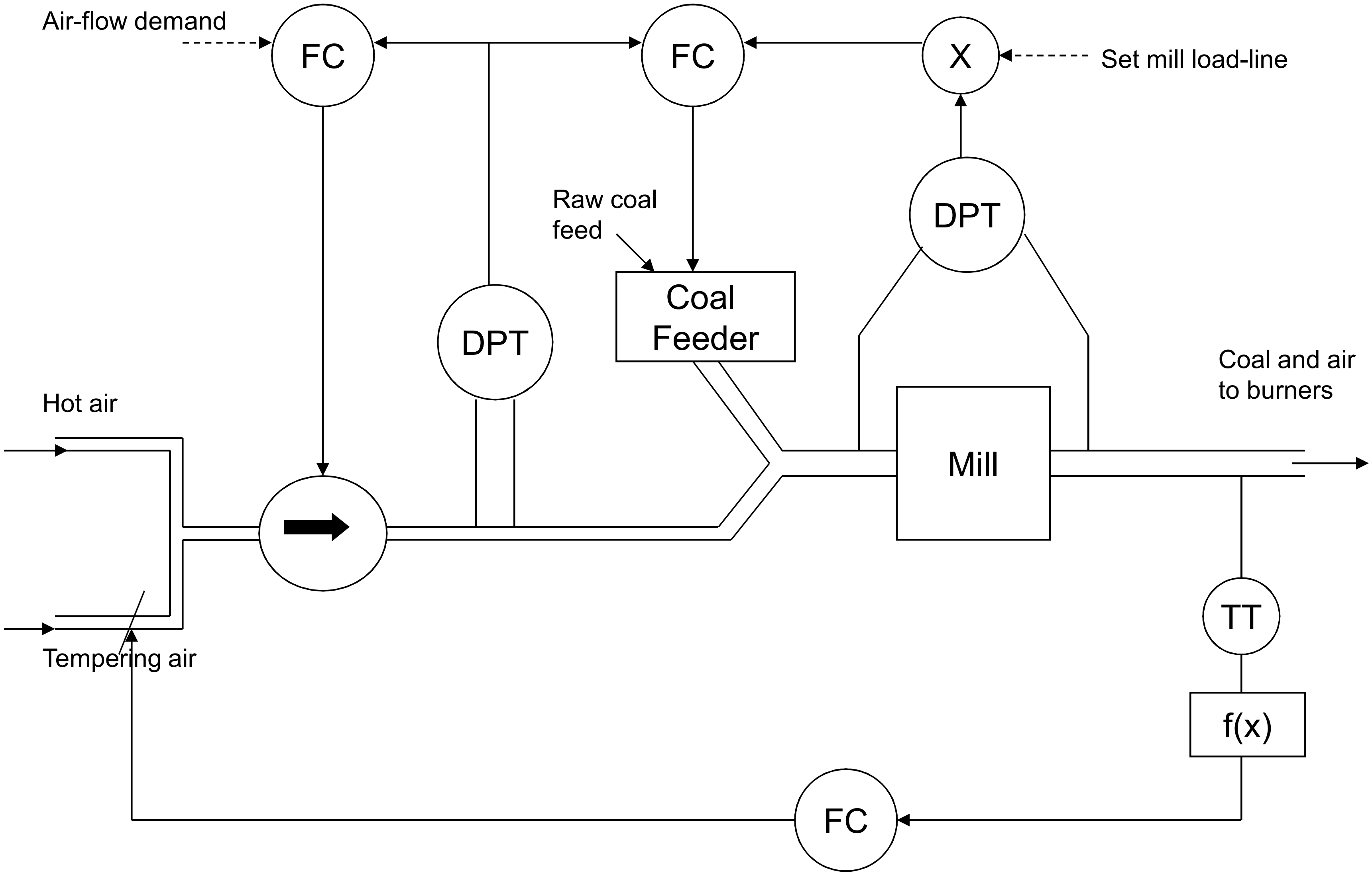
Inadequacies of the simple scheme

The response of the fuel control loop is much faster than the response of the air-flow control loop. As a result, increase in load shall cause momentary increase in fuel compared to air leading to black smoke and increased CO content. Similarly, decrease in load will lead to an Oxygen rich mixture.

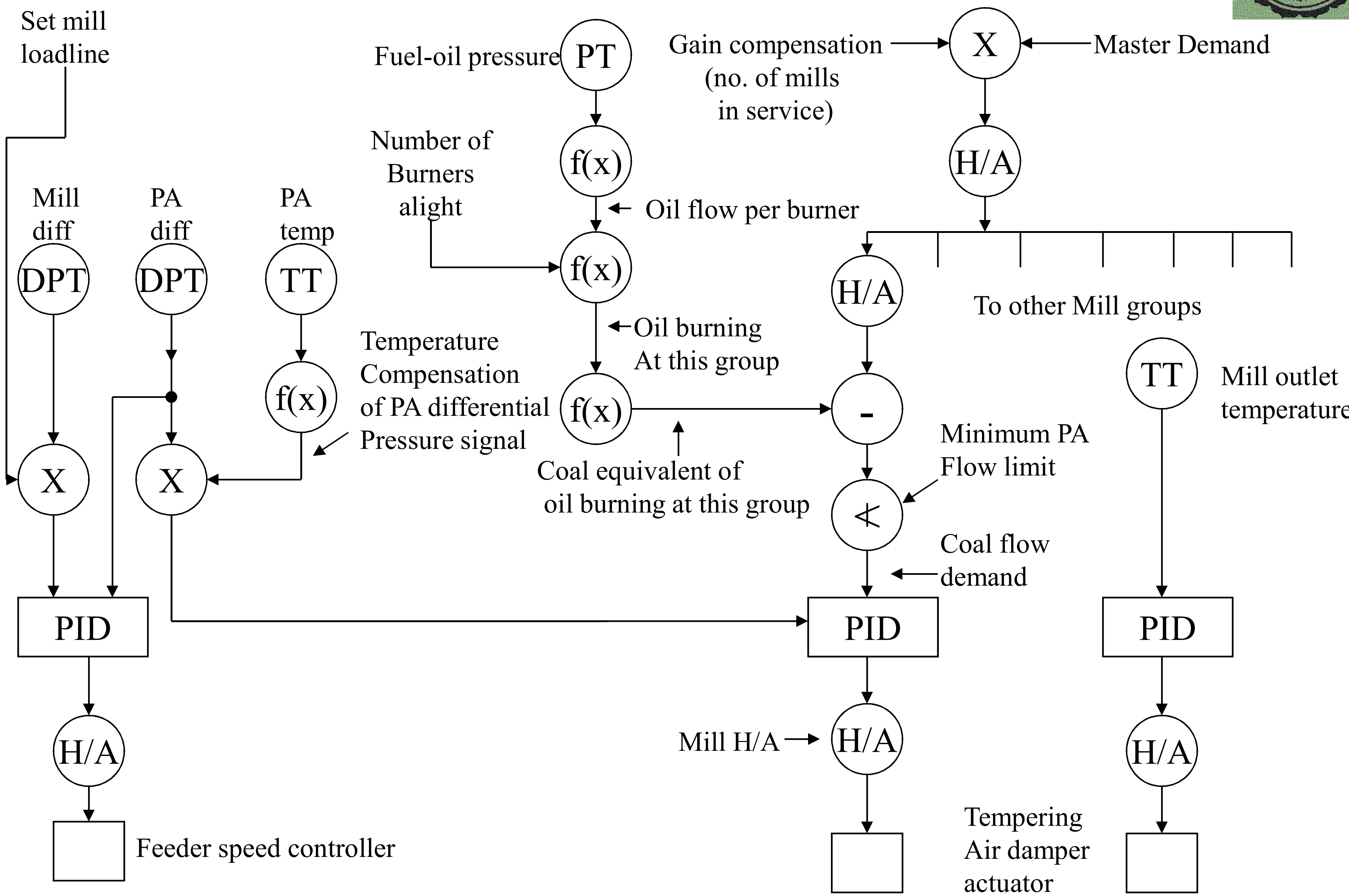
The remedy: Cross-linked scheme for an oil-fired boiler



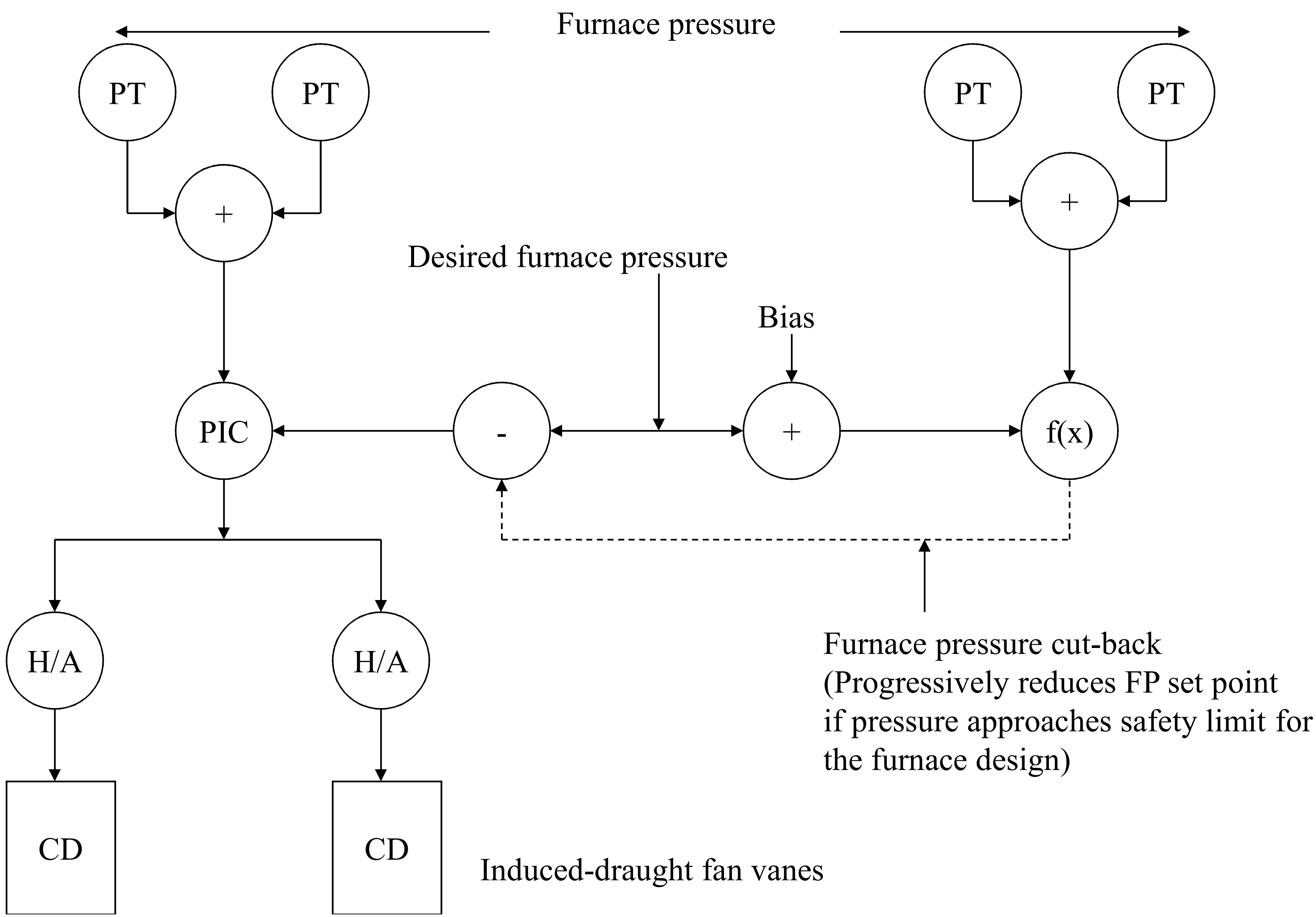
Air-fuel flow control for a a pulverizer



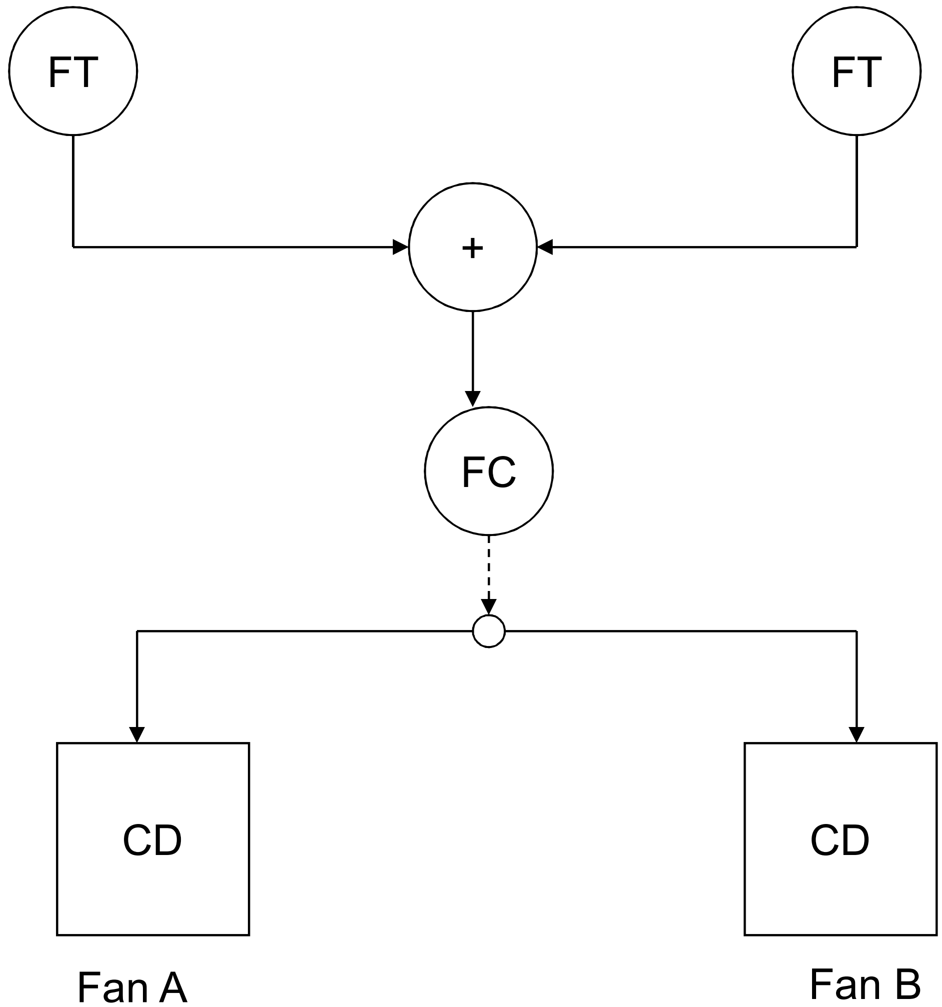
General schematic of mill control



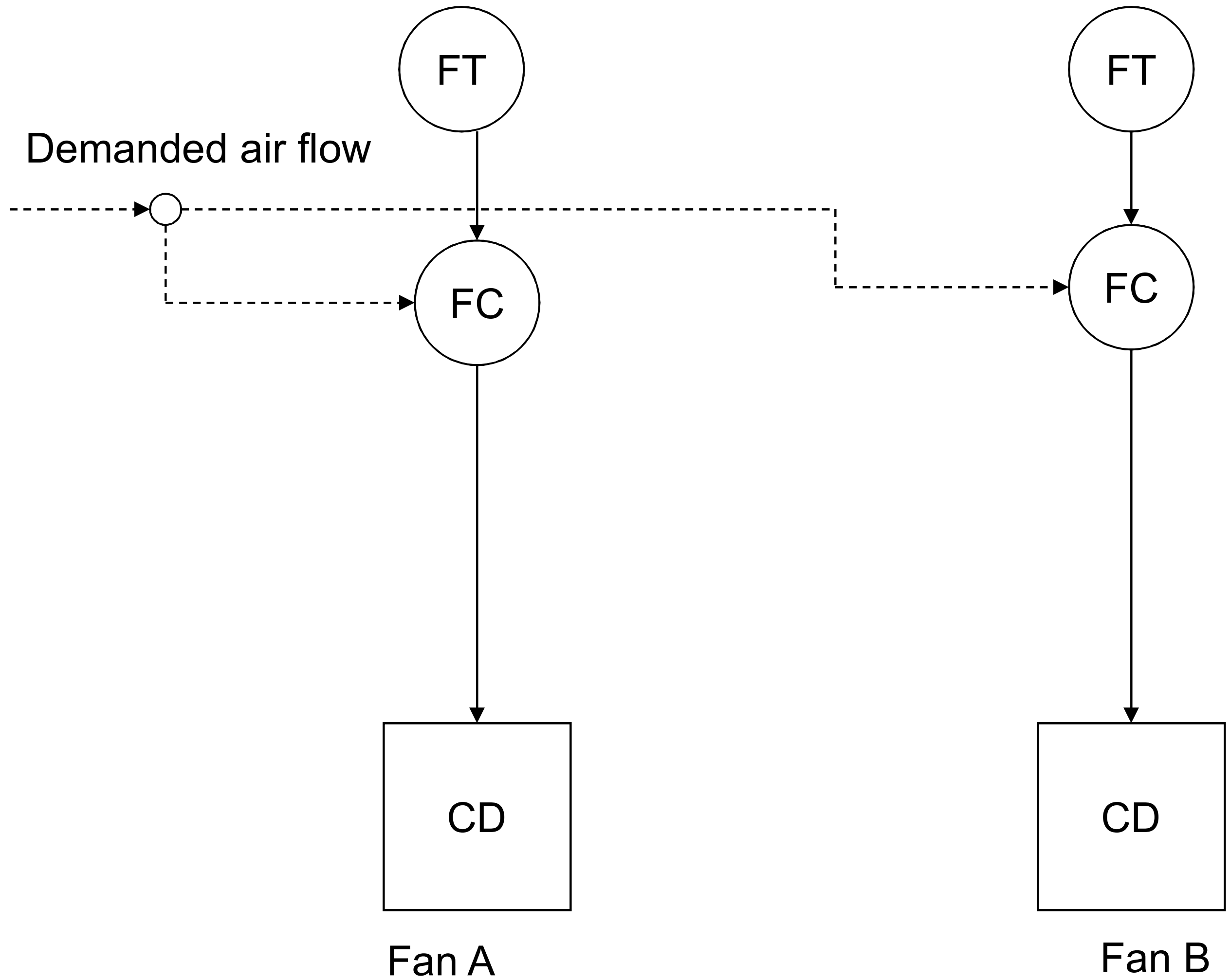
Furnace draught control



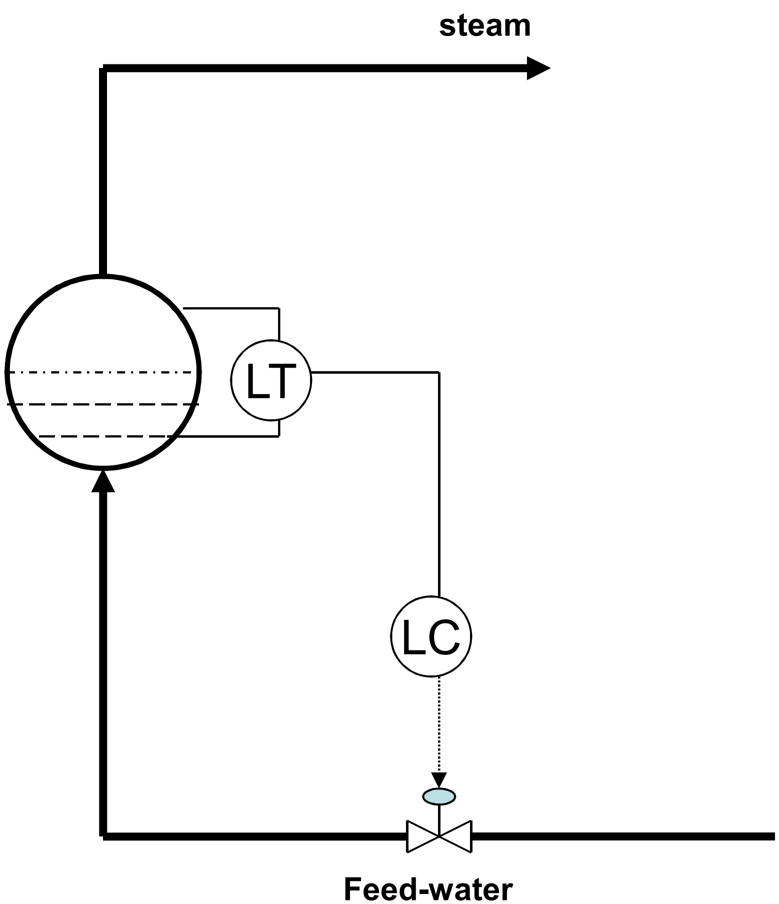
Control of air flow: Parallel Operation of FD Fans



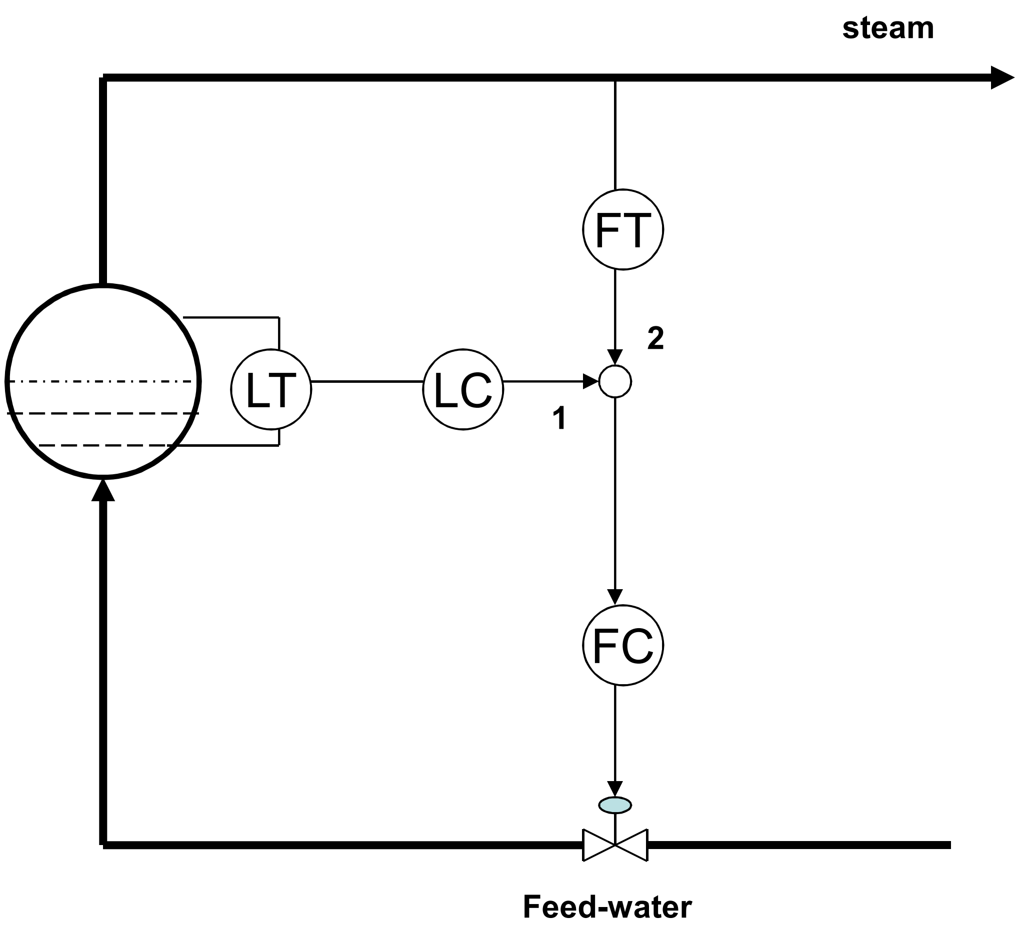
Control of air flow: Operation of FD Fans with single controllers



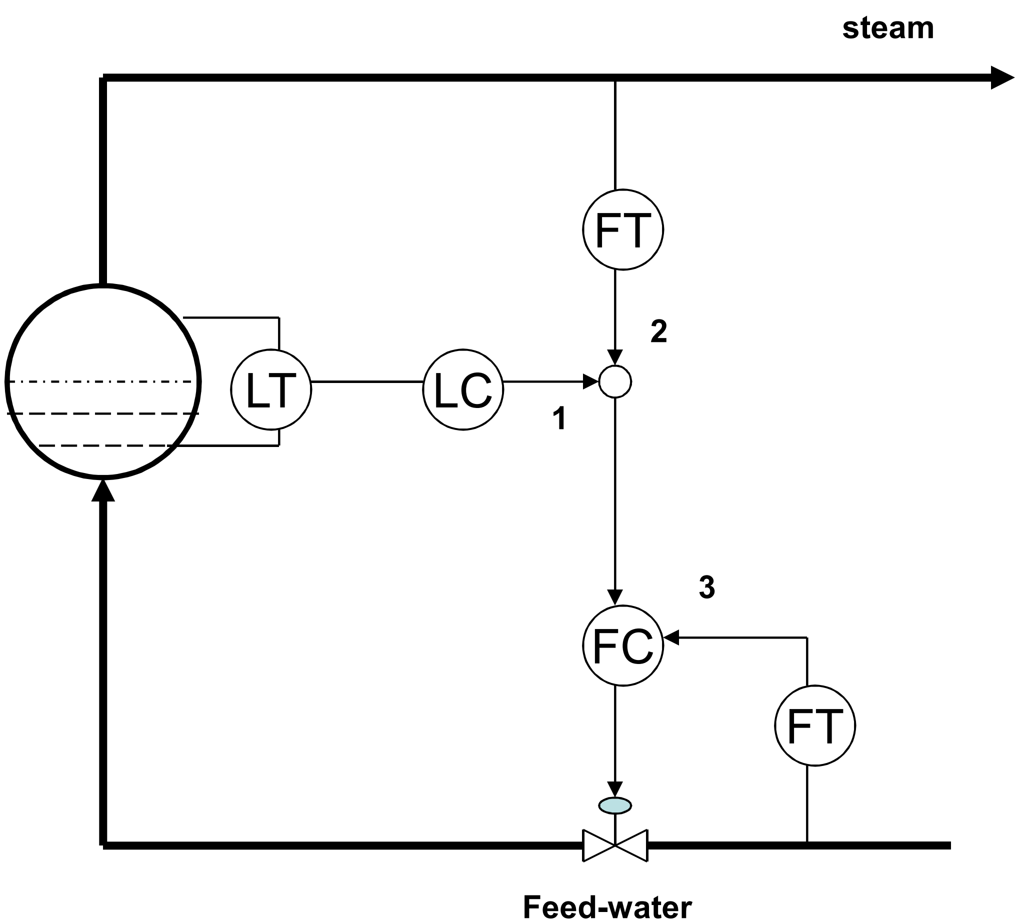
Drum-level control: Single element control



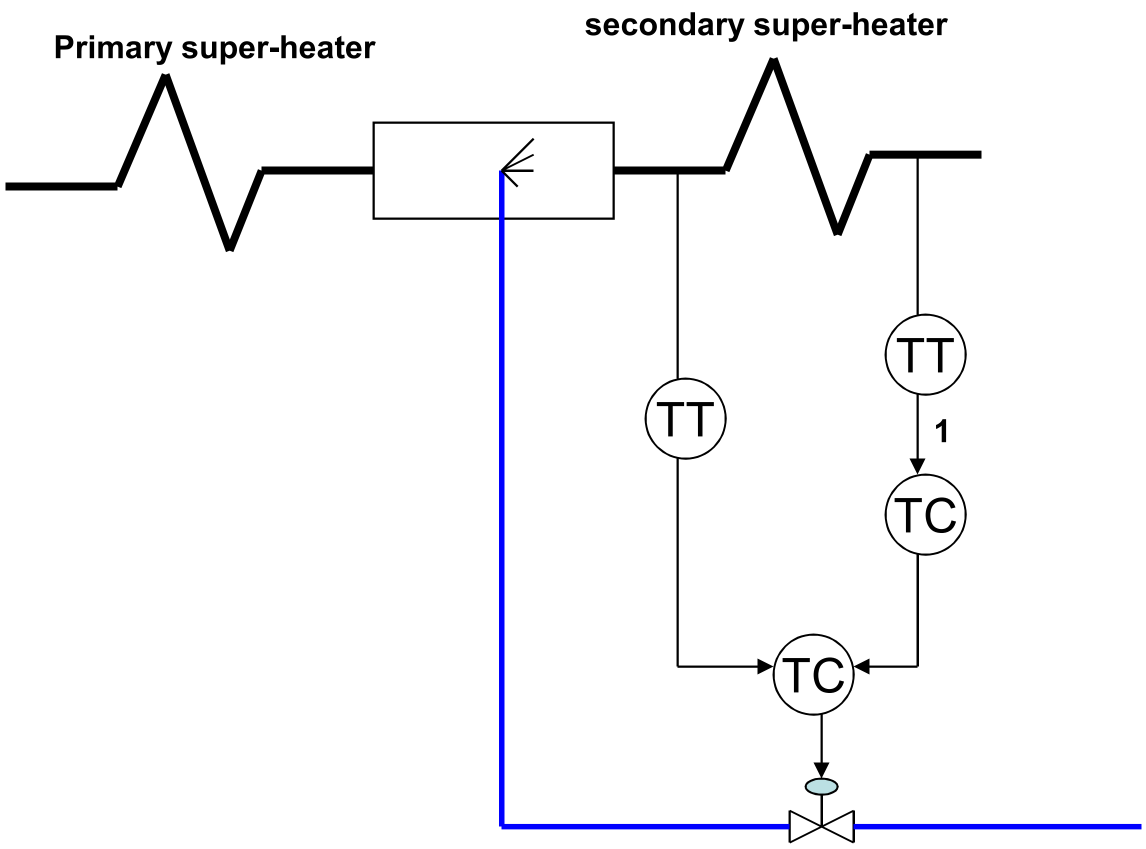
Drum-level control: Two element control



Drum-level control: Three element control

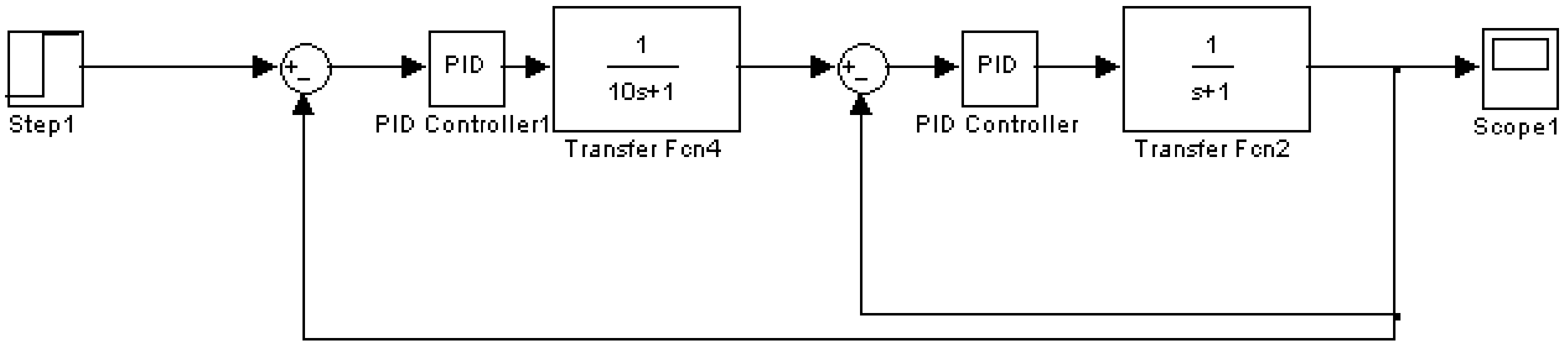


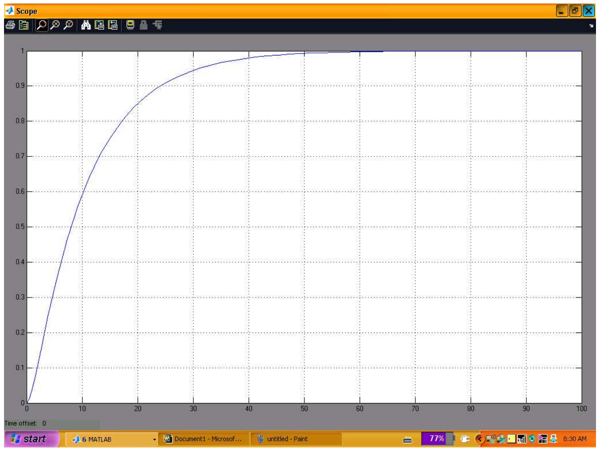
Steam temperature control

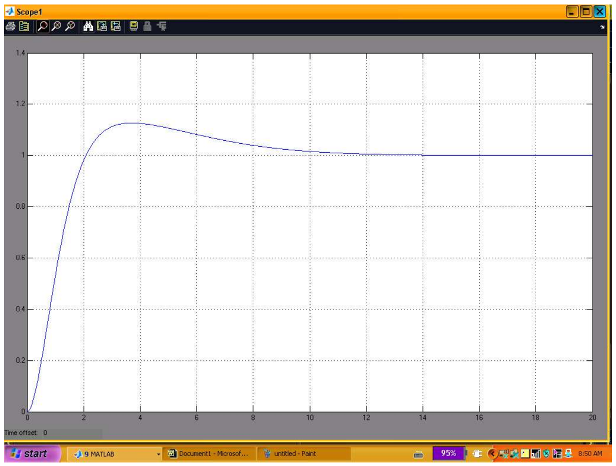


Steam temperature control: a typical cascade control action

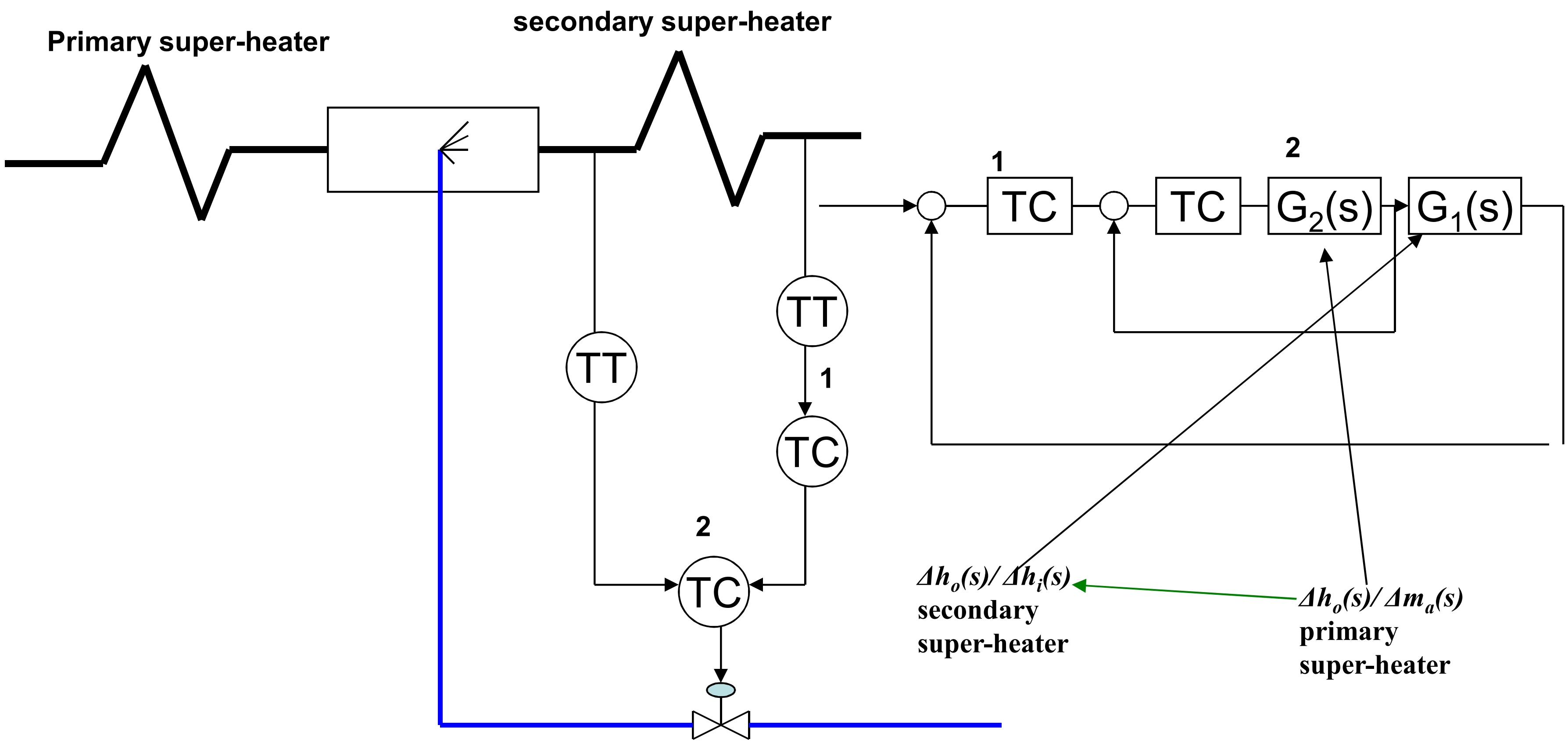
What is cascade control?



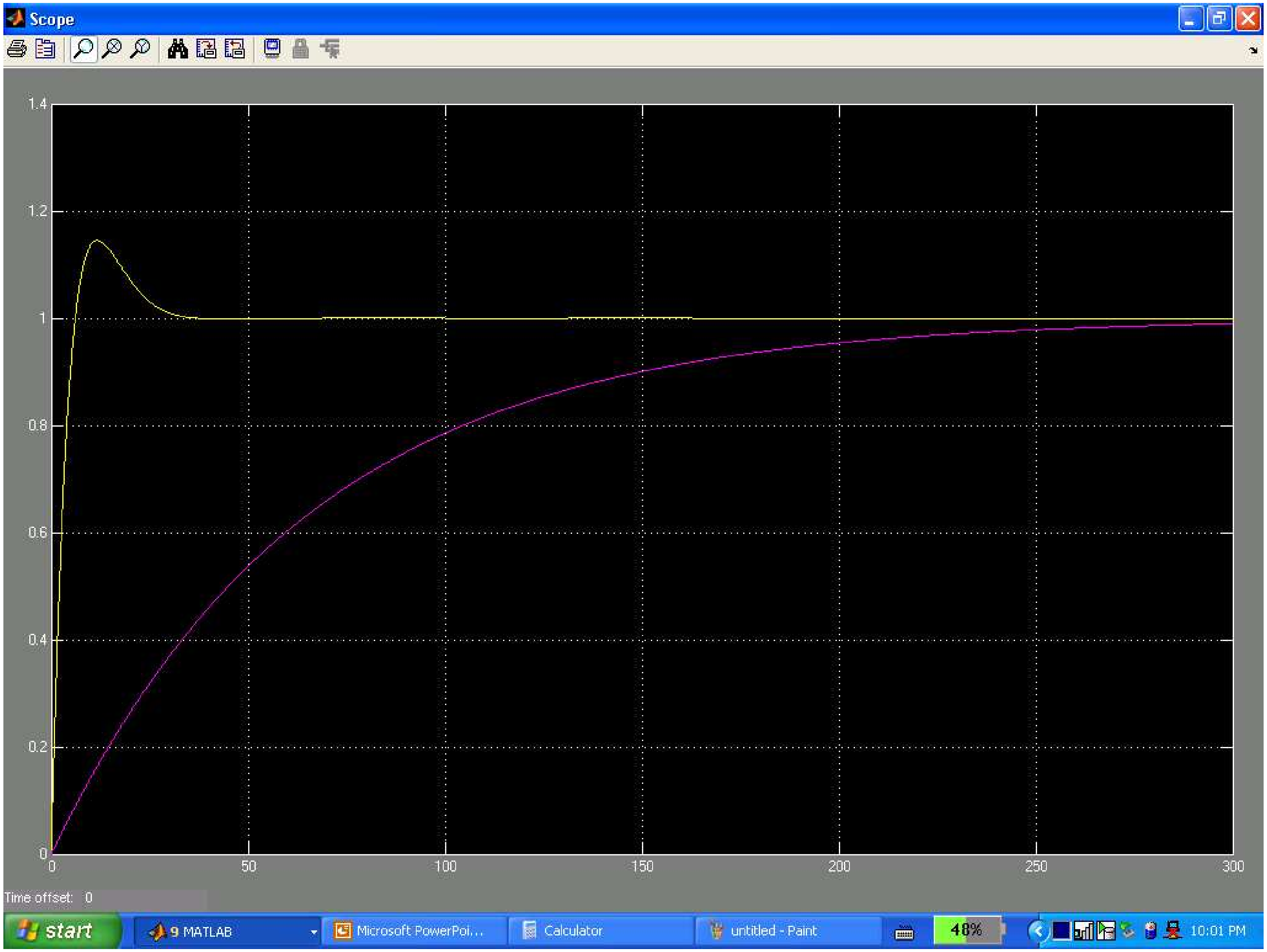




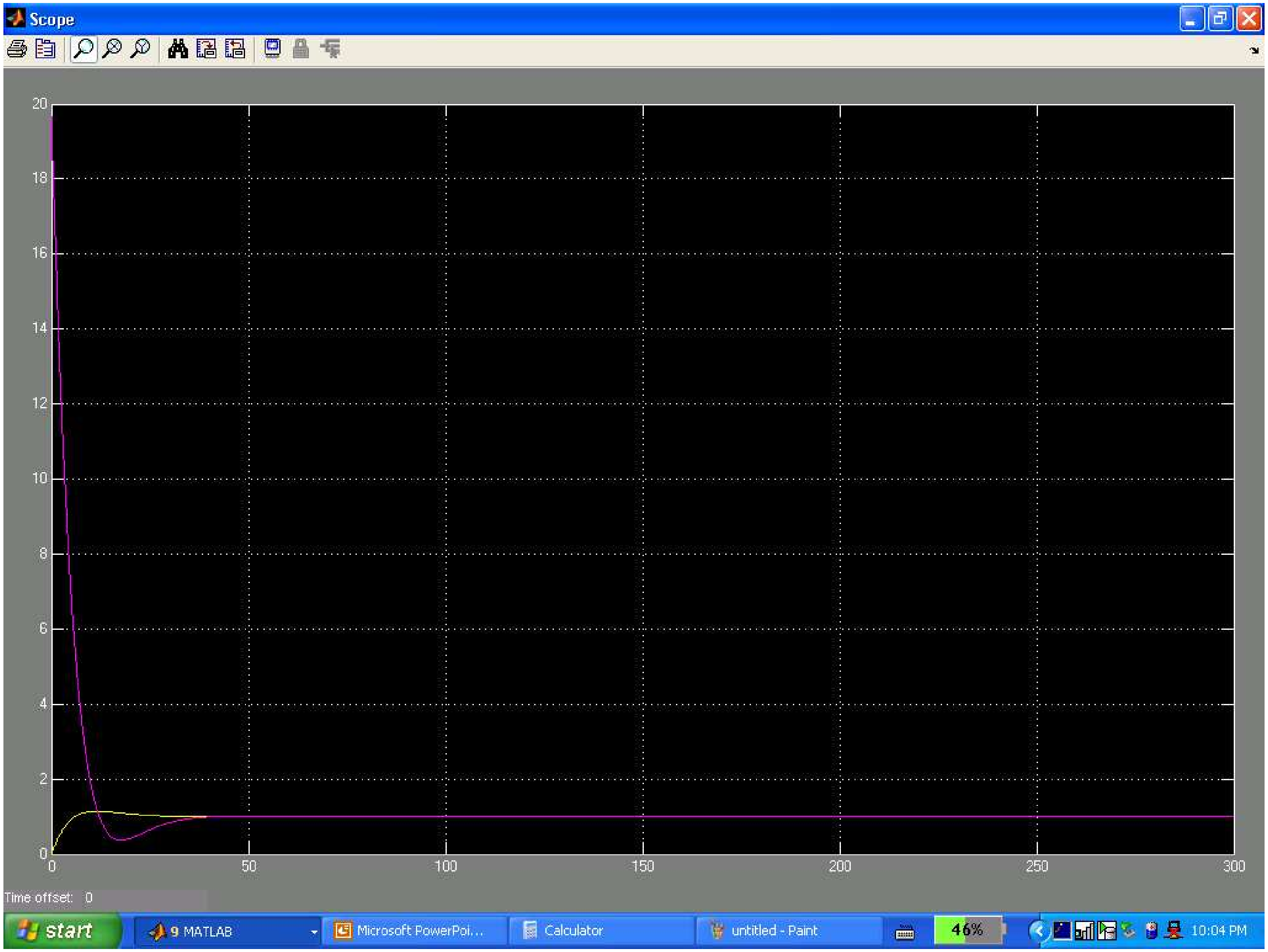
Steam temperature control



Dynamics of steam temperature control loop explained



Dynamics of steam temperature control loop explained



Dynamics of steam temperature control loop explained

$$m_i - m_0 + m_a = V\frac{d}{dt}(\rho_0)$$

$$m_i h_i - m_0 h_0 + m_a h_a + Q_{mf} = V\frac{d}{dt}(\rho_0 h_0)$$

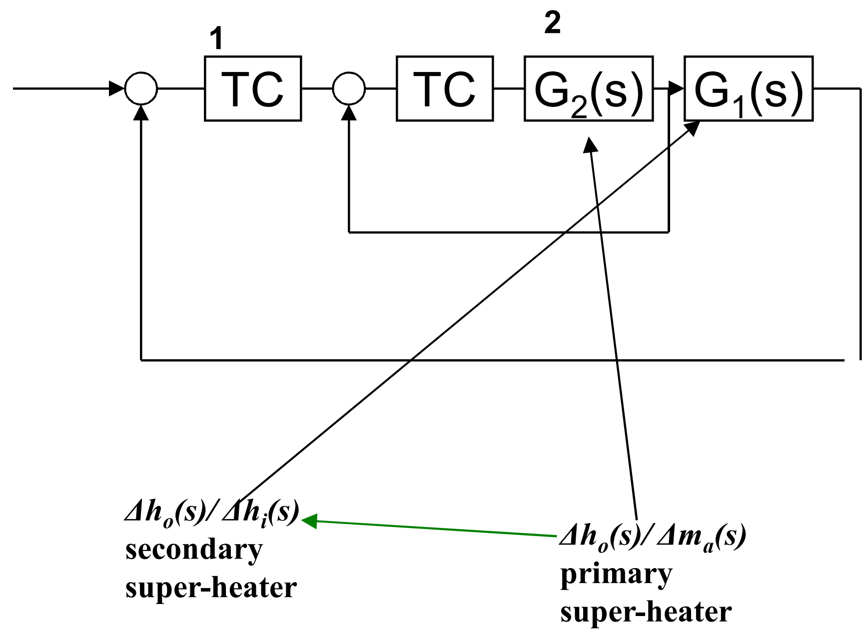
$$Q_{gm} - Q_{mf} = MC_P\frac{d}{dt}(T_m)$$

$$m_g(h_{gi} - h_{go}) - Q_{gm} = V_g\rho_g\frac{d}{dt}(h_{go})$$

$$p_0 = p_i - f.m_o^2$$

$$Q_{mf} = \alpha_{mw}a(T_m - 0.5f(h_0, p_0) - 0.5f(h_i p_i))$$

$$Q_{gm} = \alpha_{gmc}a(0.5\frac{h_{gi}}{C_{pg}} + 0.5\frac{h_{go}}{C_{pg}} - T_m)$$



Time constants of each transfer function is $\frac{\rho_{0_{ss}}V}{m_{o_{ss}}}$

Dynamics of steam temperature control loop explained

SL. No.	Parameter	Value
1	V	0.102 m^3
2	V_g	35.04 m^3
3	M	380.3 kg
4	a	11.8 m^2
5	ρ_o	1000 kg/m^3
6	ρ_g	0.67 kg/m^3
7	f	35.96
8	C_p	0.47 kJ/kg.K
9	C_{pg}	1.41 kJ/kg.K
10	α_{ms}	140.0 $W/m^2.K$
11	α_{gmc}	30.0 $W/m^2.K$

Auxiliary control loops

The typical auxiliary control loops are the following:

- Closed cycle cooling water system
- Feedwater heater level control
- De-aerator storage tank and hotwell level control
- Boiler feed-pump recirculation control
- Controls associated with air heater

Control using digital hardware

Programmable Logic Controllers

Typically for on-off controls mainly those which are not affected by change of plant operating conditions.

Distributed Control Systems

- Boiler controls, including the combustion (firing rate) furnace draft, steam temperature and feed-water control loops.
- Burner control and pulverizer control
- Control loops in the plant auxiliary systems that need to be monitored and/or operated the main control room.
- Data acquisition and reporting functions

Model predictive control

- Usually employs an estimation algorithm for correction of control inputs to tackle uncertainties

- Can be used for multi-regime operation

Example: Use of a simulator to correct the demand for steam with compensation for bled steam in co-ordinated control

Conclusion

Use of thermal energy is older than civilization itself- mankind mastered lighting a fire much before learning to draw or write.

Harnessing thermal energy to produce electricity is as old as old man Faraday himself, but the technology for this is ever evolving and always in a nascent state.

Thank you….