Agenda

1. Introduction
2. Definition & Purpose of Control
3. Process Control Terms
4. Feedback & Feedforward Control
5. HEI Requirements for C&I
6. Turbine Back Pressure Control
7. When to Use 1-Speed, 2-Speed Motors or VFD’s
8. Rules of Step Switching
9. Drain Pot Level Control & Condensate Tank Level Control
10. ACC Freeze Protection
11. Typical C&I Scope for the ACC Supplier
12. Q&A

Company Introduction

Joint Venture:

TIME FOR A COOL CHANGE

Tube Bundle Production Factory

100,000 ft^2 Factory in Dangjin, South Korea

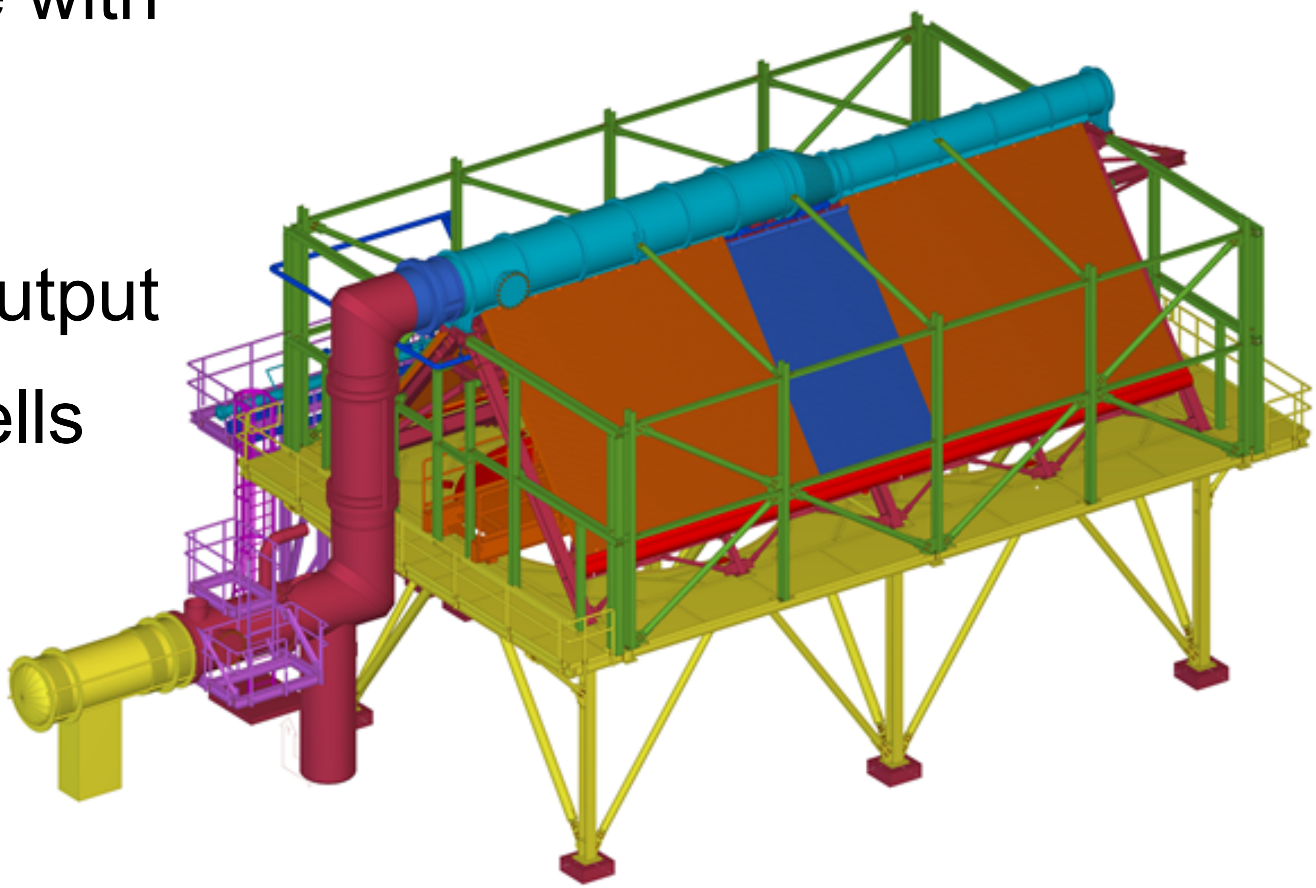
Tube Bundle Production Factory

State of the Art Factory

ACC Control – Case Study 1

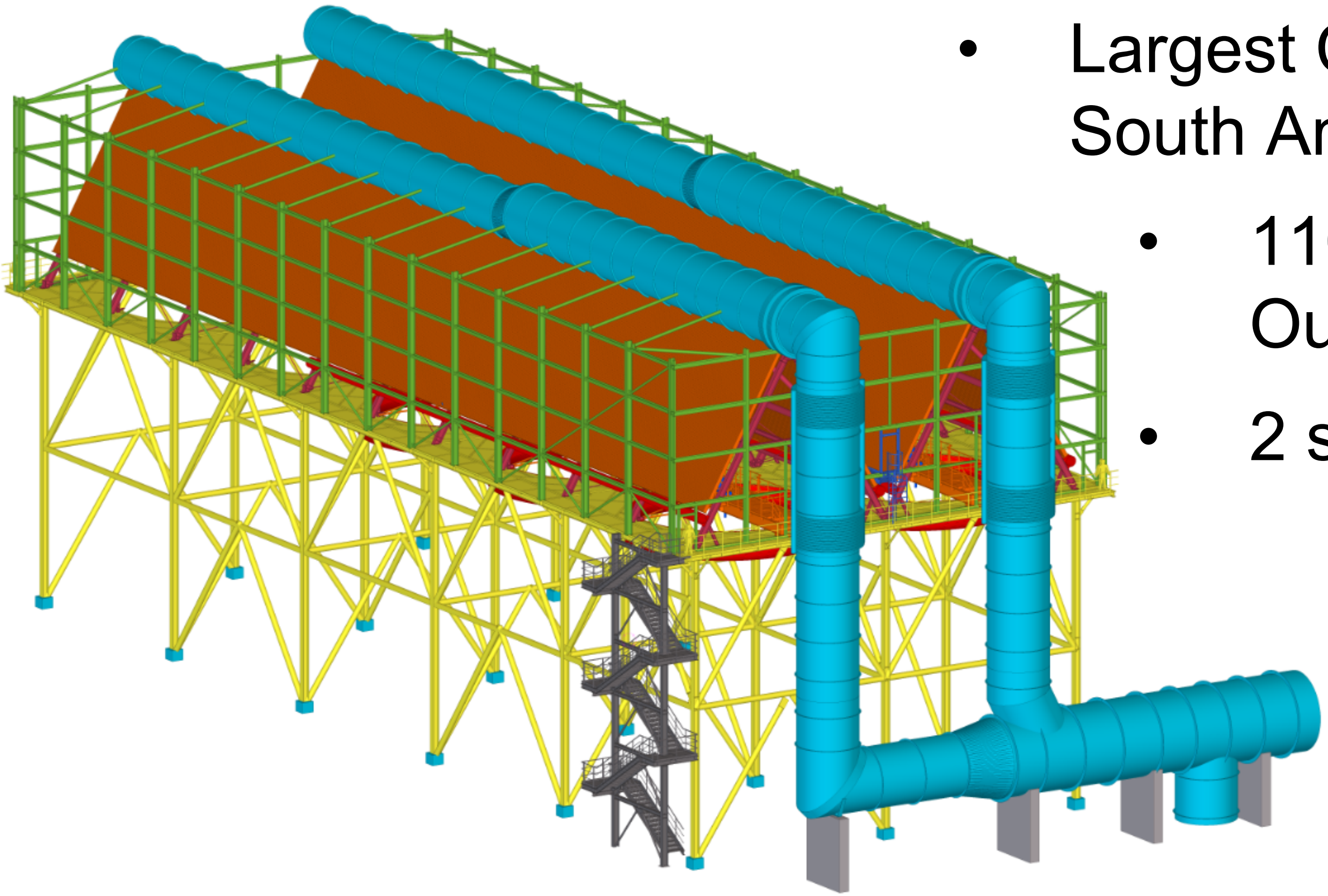
Baja California IV ACC - Mexico

- Abener/Abengoa
- Diesel Engine with Waste Heat Recovery
- 5 MW STG Output
- 1 street x 2 cells



ACC Control – Case Study 2

Cerro Dominador ACC - Chile

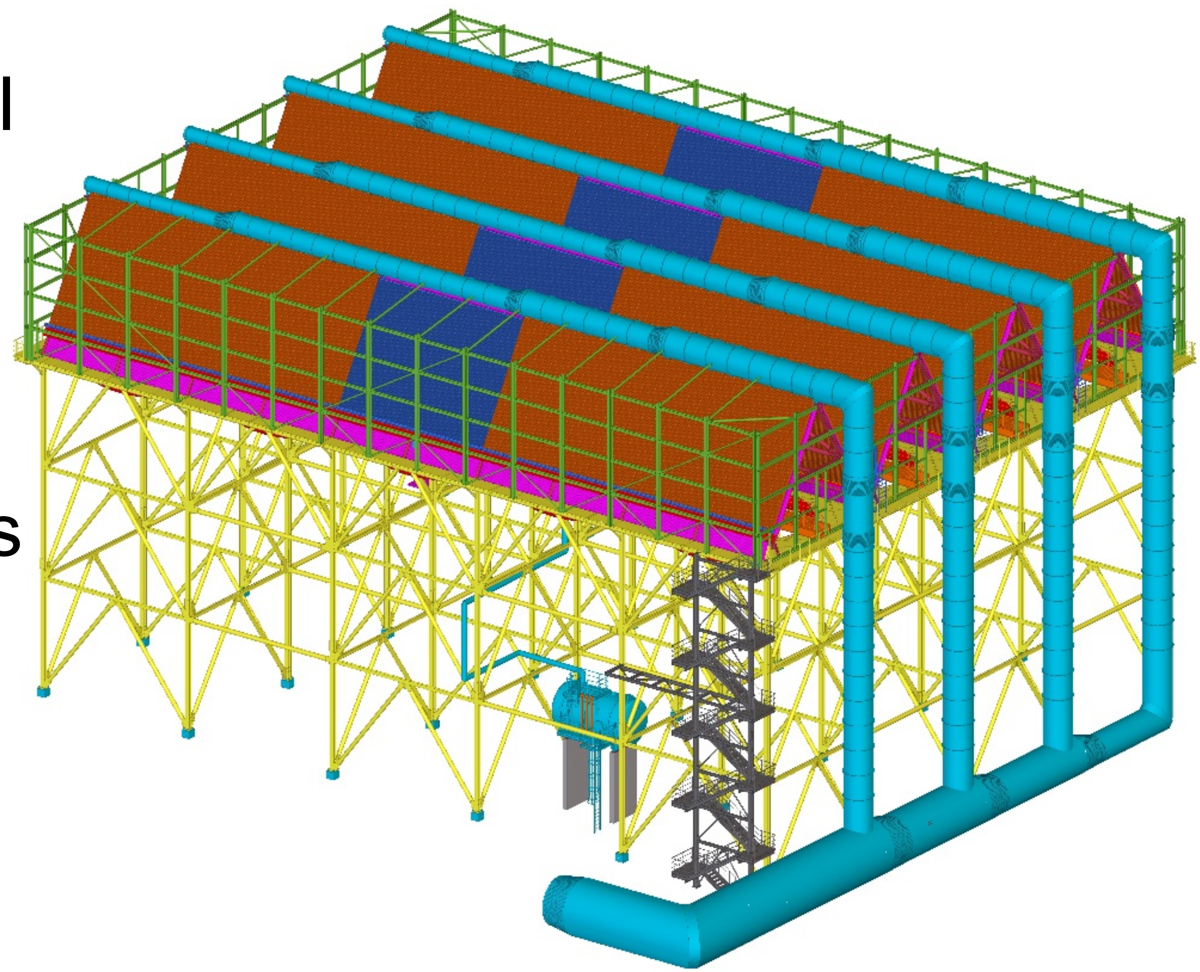


- Abeinsa Energy
- Largest CSP plant in South America
  - 110 MW STG Output
  - 2 streets x 5 cells

ACC Control – Case Study 3

SNG ACC – South Korea

- POSCO E&C
- Synthetic Natural Gas Plant
- 97 MW STG Output
- 4 streets x 5 cells



TIME FOR A COOL CHANGE

Air Cooled Condenser Users Group

Technical Discussion
ACC Control

Definition & purpose of control

Control = regulation of all aspects of the process

→ Precise control of level, temperature, pressure and flow is important in many process applications (including ACC's)

Purpose of control:

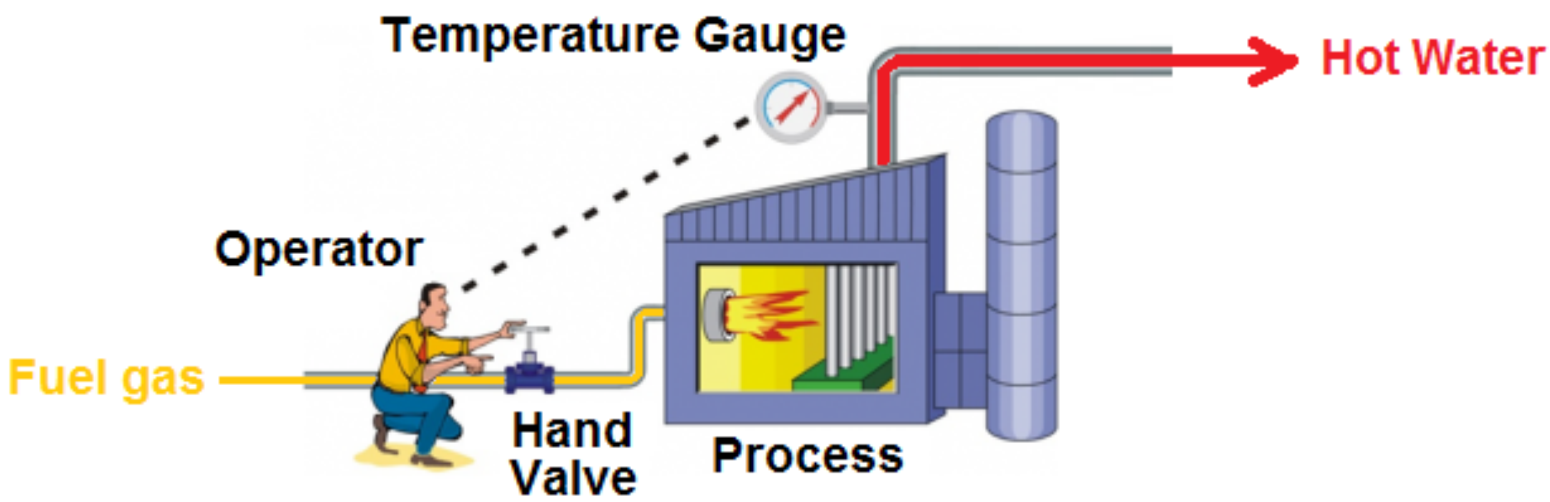
1. Reduce variability (keep pressure constant for example)
2. Increase efficiency (reduce auxiliary power consumption)
3. Ensure safety & protect equipment (do not exceed design pressure/temp)

Control in ACC's:

- TBP must be controlled (avoid turbine trip, increase steam turbine output, reduce auxiliary power consumption, limit fluctuations in pressure)
- Pressure & temperature should be limited (protect equipment)
- Liquid level in tanks should be maintained (protect equipment)
- Condensate flow in SJAE should be maintained (protect equipment)

Manual and automatic control

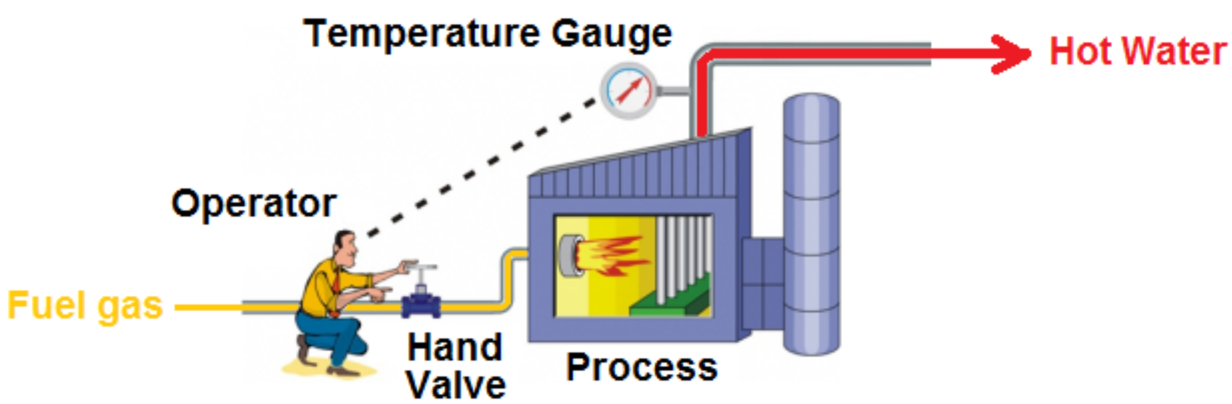
<u>Manual control</u>: all regulation tasks will have to be done manually.



<u>Example</u>: To keep constant the temperature of the water discharged from a gas-fired heater, an operator will have to watch a temperature gauge and adjust a fuel gas valve accordingly. If the water temperature becomes too high for some reason, the operator has to close the fuel gas valve a little bit, just enough to bring the temperature back to the desired value.
If the water becomes too cold, he has to open the fuel gas valve.

Manual and automatic control

<u>Feedback control</u>: The control task done by the operator is called feedback control, because the operator changes the firing rate based on feedback that he gets from the process via the temperature gauge.

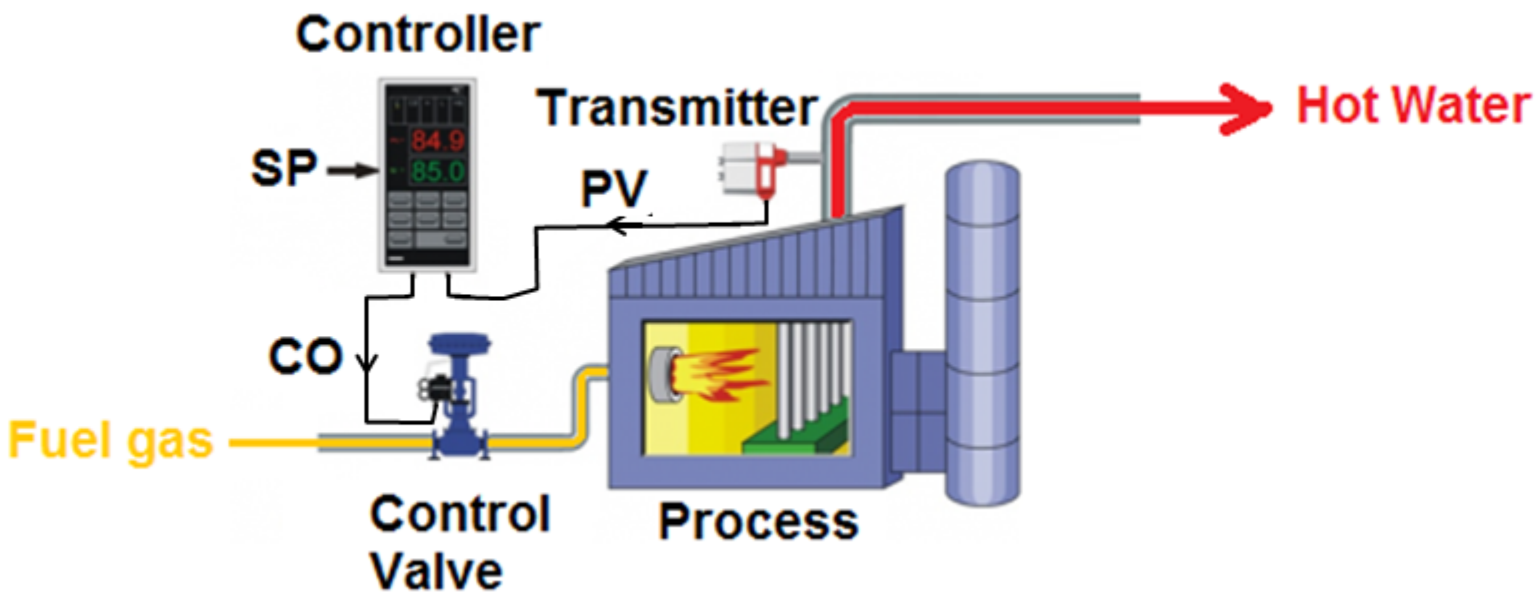


<u>Control loop</u>: The operator, valve, process, and temperature gauge form a control loop. Any change the operator makes to the gas valve affects the temperature which is fed back to the operator, thereby closing the loop.

Manual and automatic control

<u>Automatic control</u>: the control loop can be automated in the following way:

- Install a temperature transmitter to measure the process variable (PV)
- Using a control valve with an actuator (and positioner)
- Installation of a controller; the controller output (CO) sets the valve position

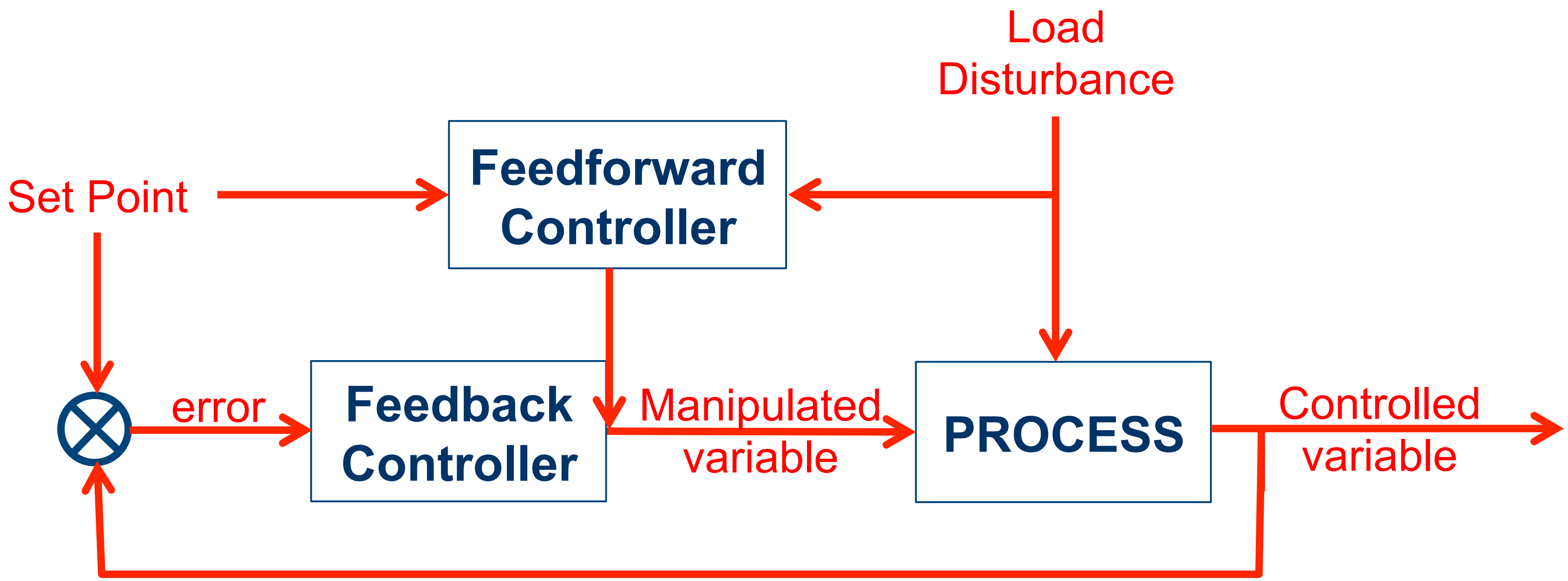


The controller has a set point (SP) that the operator can set to the desired value for the temperature of the hot water.

Process control terms

- A process variable is a condition of the process fluid (pressure, flow, temperature, level, pH, etc.).
- The setpoint (SP) is a value for a process variable that is desired to be maintained.
- The measured or controlled variable is the condition of the process fluid that is measured or is related to the process variable. In most cases the process variable is also the measured variable.
- Error: difference between the measured variable and the setpoint.
- A load disturbance is an undesired change in one of the factors that can affect the process variable.
- A closed control loop exists where a process variable is measured, compared to a SP, & action is taken to correct deviation from the setpoint.
- A controller is a device that receives data from a measurement instrument, compares that data to a programmed setpoint, and, if necessary, signals a control element to take corrective action (adjustment).

Feedback & Feedforward control

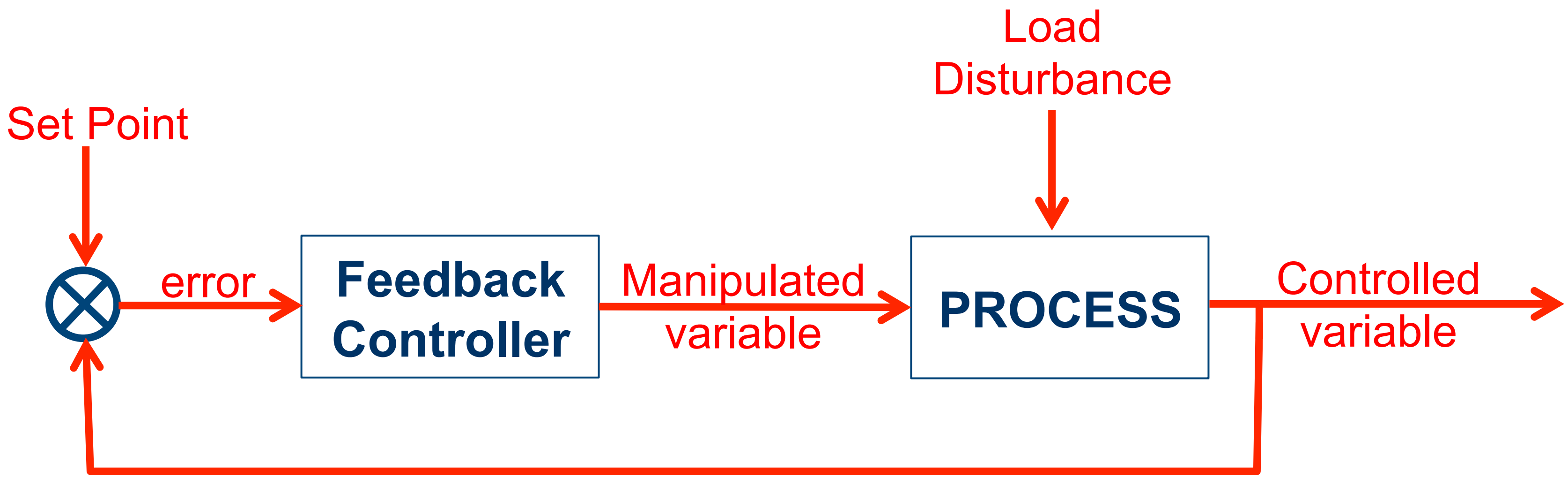


Feedback control: measures a process variable (PV) and sends the measurement to the controller for comparison to the setpoint (SP).
If the PV is not at SP, control action is taken through the manipulated variable to return the PV to the SP. Feedback is the most commonly used control loop.

Advantage: it directly controls the PV (or controlled variable).

Disadvantage: PV must leave the SP for action to be taken.

Process control concepts applied to ACC's



<u>Process control terminology applied to ACC's:</u>

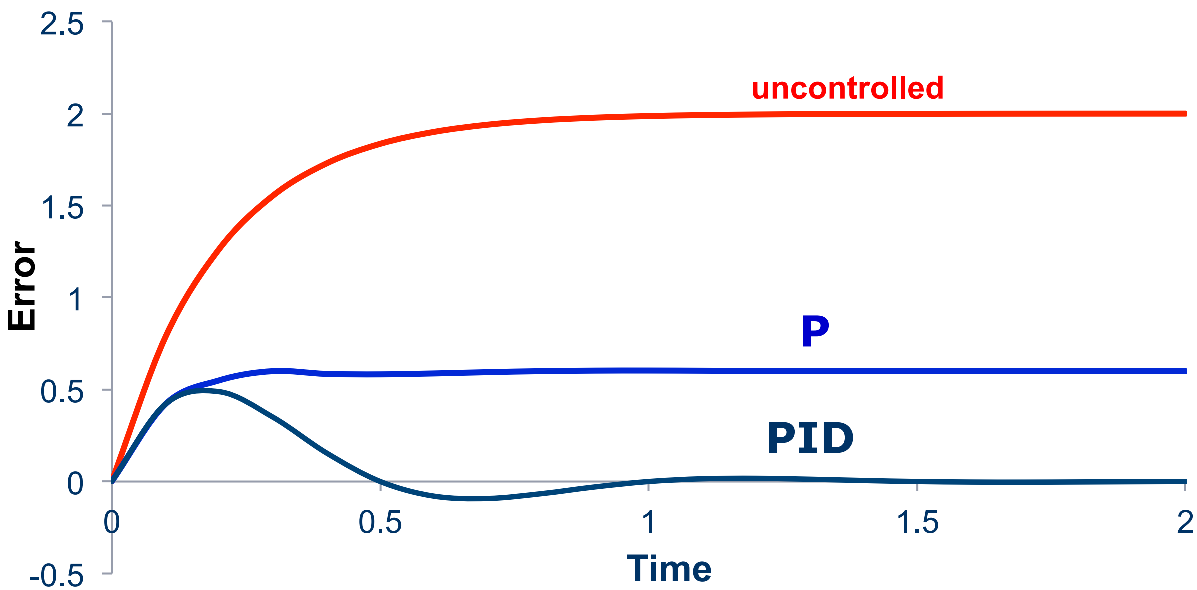
- Process: condensation of steam
- Controlled variable: turbine back pressure
- Manipulated variable: ACC condensing capacity (fan control steps)
- Load disturbance: change in air inlet temperature, steam flow rate, etc.
- Set point: desired value for the turbine back pressure
- Feedback controller: before → analog controller like P, PI or PID controller, in modern power plants a DCS is used.

Controller algoritms

Controller output: (remind that error (e) = PV – SP)

- How much → proportional (P) mode (MV proportional to e)
- How long → integral (I) mode: As long as e ≠ 0 the I-mode will continue to increment or decrement the controller's output to reduce e. Given enough time, I-action will drive the MV far enough to reduce the error to zero
- How fast → derivative (D) mode

Proportional action will not return the PV to the SP (there will be an OFFSET):



→ **PI or PID control is preferred over P**

HEI requirement for C&I in an ACC

Recommended instrumentation for ACC’s (per HEI):

- TBP & Steam temperature: minimum 1 PT + minimum 1 TT
- Condensate tank liquid temperature: minimum 1 TT
- Temperature condensate headers: minimum 1 TT per header
- Temperature non-condensables: minimum 1 TT per street
- Drain pot level: minimum 1 LT
- Condensate tank level: minimum 1 LT
- Gearbox oil pressure/flow: minimum 1 switch
- Fan speed: fan motor speed status for each fan
- Vibration air moving equipment: minimum 1 switch per assembly

HEI requirement for C&I

General ACC control concepts:

- ➢ TBP is controlled by modifying the air flow rate
- ➢ # fan control steps is function of type of motor control (& # isolation valves)

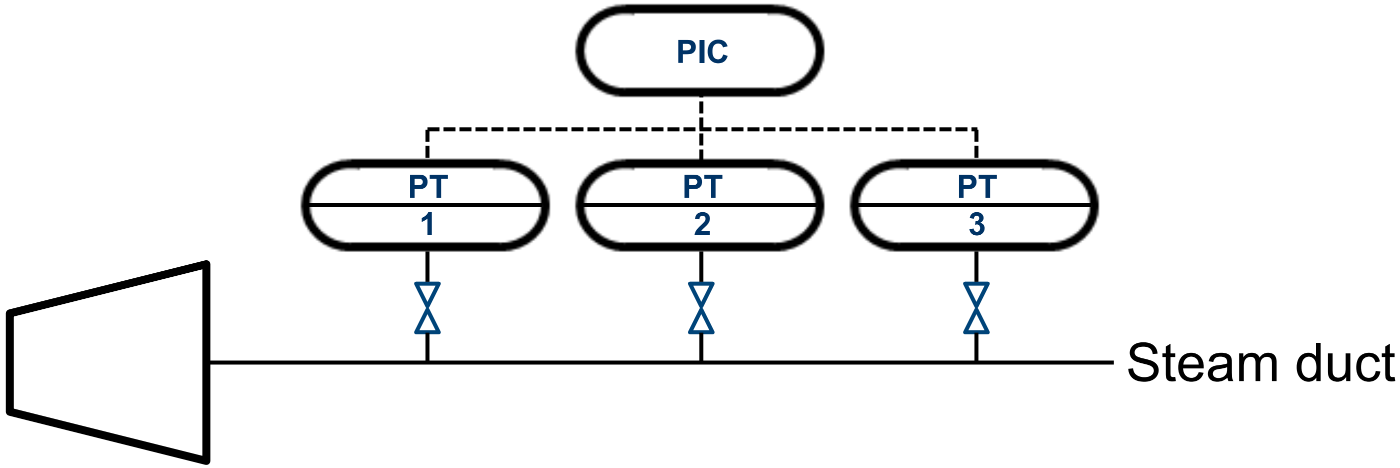
Type of motor control:

- Single speed motors
- Two speed motors
- Variable speed motors (using VFD's)

When to use single speed, two speed or VFD's?
→ this will be illustrated using ACC references that have a different number of cells

Control of the turbine back pressure (TBP)

Instrumentation foreseen on an ACC for TBP control:



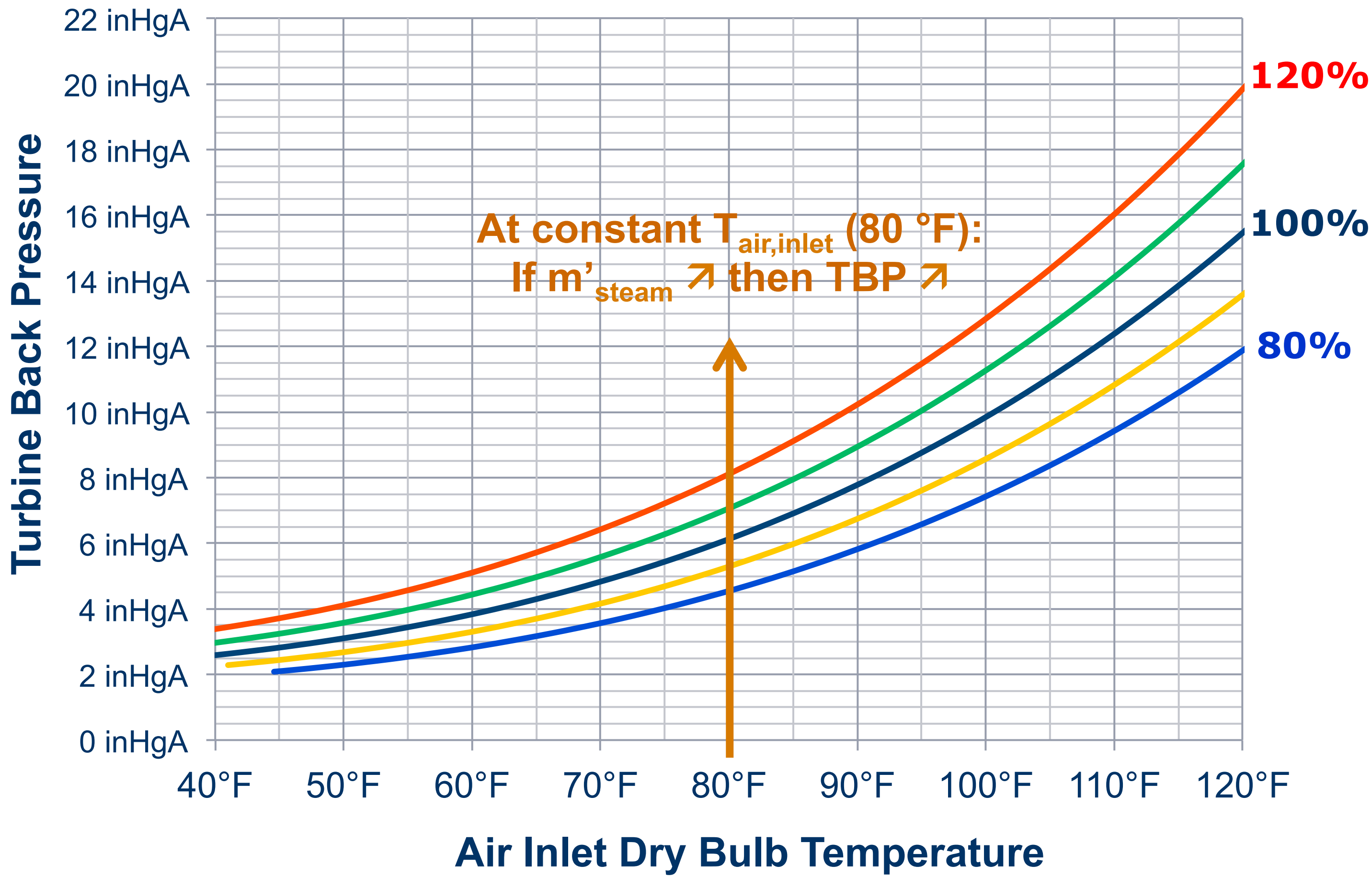
ACC control refers to turbine back pressure (TBP) control:

The control system selects the appropriate condensing capacity (fan control step) as function of the measured value of the TBP in response to variations in:

- Ambient air temperature
- Steam flow rate to the ACC
- Other load disturbances

The control system will maintain the TBP around the selected set point.

Impact of Load disturbances on the TBP



Increase in $T_{air,inlet}$ or m'_{steam} → increase in TBP (performance curves)

ACC control & changing condensing capacity

Control variables in an ACC:

- Process Variable (PV) which is also the Controlled Variable (CV) = TBP
- Major load disturbances (L): $T_{air,inlet}$ and m'_{steam}
- Manipulated Variable (MV) → condensing capacity (fan control steps)

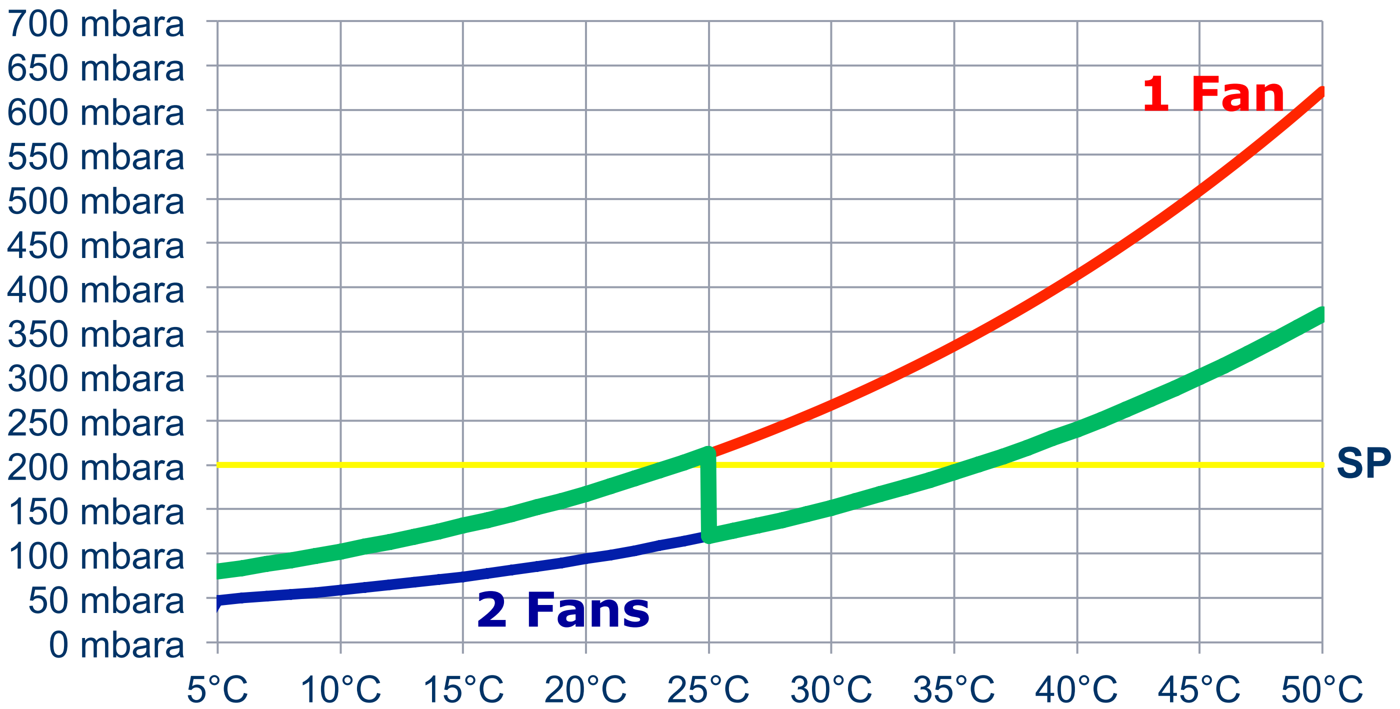
How to change the ACC condensing capacity (MV):

- Change air flow rate → change fan speed, # fans in operation
- Change available HX surface area → use steam isolation valves (isolation valves are not always available and should be avoided if possible)

Most common way → change fan speed (fan control steps)

Baja California IV project (Mexico): 2 cells

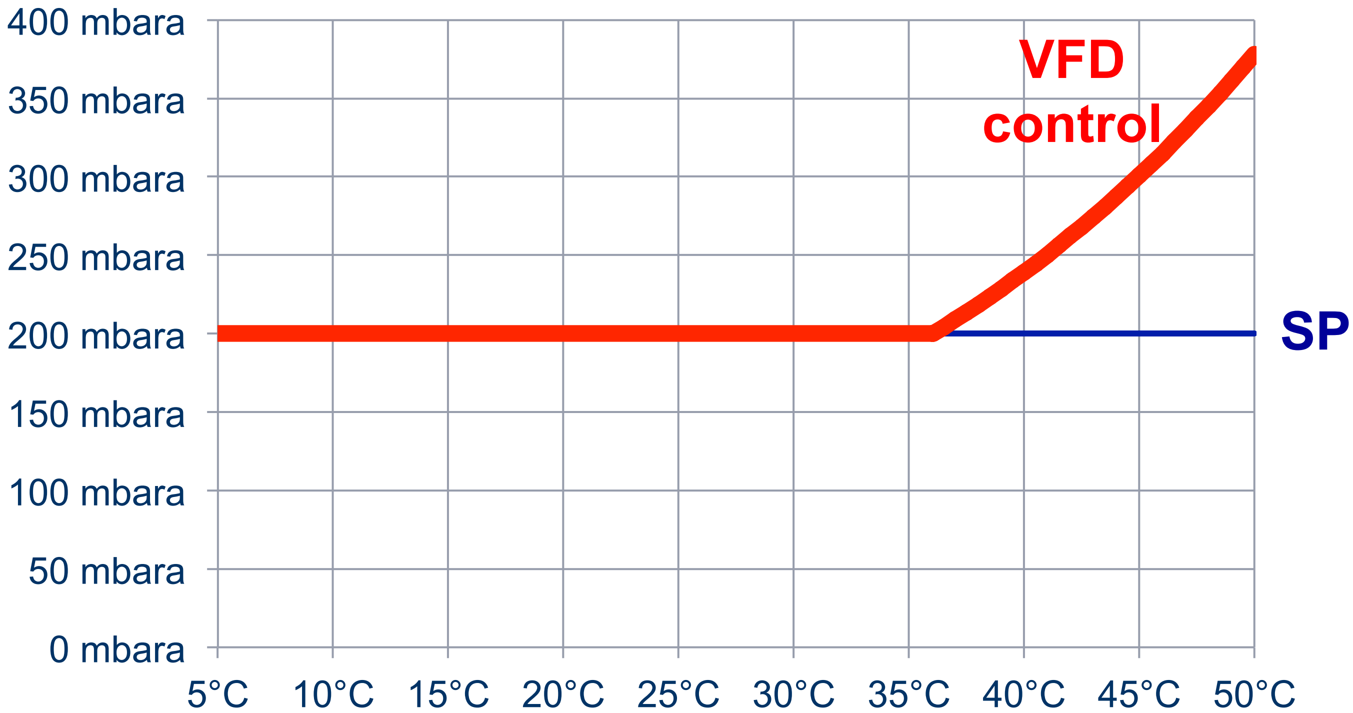
Is control with single speed motors possible for a 2 cell ACC?



Below 25 °C: 1 fan in operation; at 25 °C and up: 2 fans in operation
→ At 25 °C: TBP reduction of almost 100 mbar (not feasible for control)

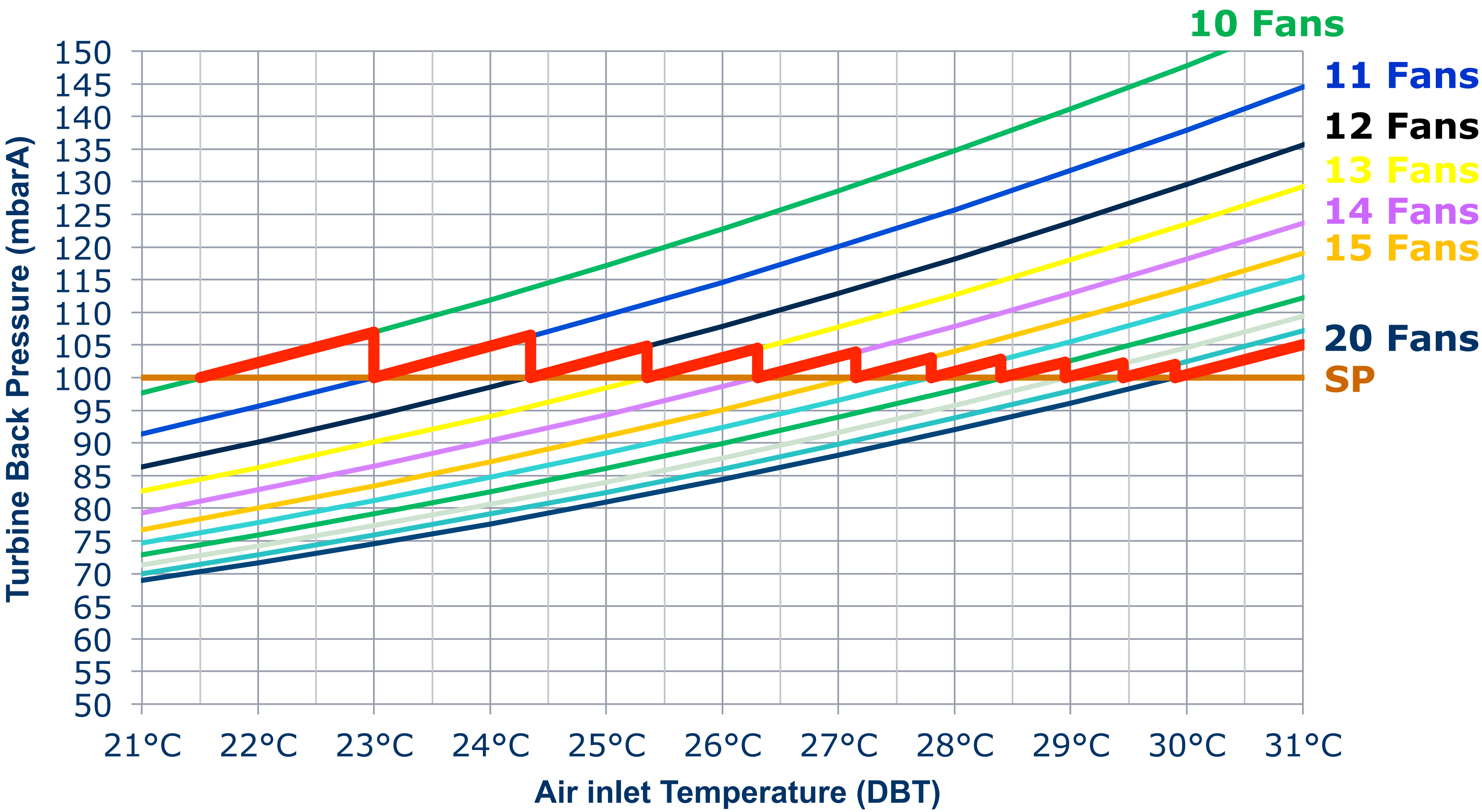
Baja California IV project (Mexico): 2 cells

VFD's were recommended for TBP control:



TBP can be maintained at SP as long as ACC condensing capacity is sufficient

POSCO SNG project (Korea): 4 x 5 cells



Switch between consecutive fan control steps → Δp < 10 mbar

For 20 cell ACC: single speed motors are OK for control purposes

Cerro Dominador project (Chile): 2 x 5 cells

Rule of thumb: Δ capacity between 2 fan control steps ≈ 5% ± 2% (but < 10%)

<u>Assumptions</u>:

- Fan off → 0% cell capacity (conservative)
- Fan ½ speed (HS) → 50% cell capacity
- Fan full speed (FS) → 100% cell capacity

Single speed motors do not provide sufficient control flexibility, since switching off 1 fan would result in a decrease of about 10% condensing capacity for a 10 cell ACC
→ Two speed motors for each cell selected:

STEP	FS	HS	OFF	Capacity
1	0	0	10	0%
2	0	1	9	5%
3	0	2	8	10%
4	0	3	7	15%
5	0	4	6	20%
6	0	5	5	25%
7	0	6	4	30%
8	0	7	3	35%
9	0	8	2	40%
10	0	9	1	45%
11	0	10	0	50%
12	5	1	4	55%
13	5	2	3	60%
14	5	3	2	65%
15	5	4	1	70%
16	5	5	0	75%
17	6	4	0	80%
18	7	3	0	85%
19	8	2	0	90%
20	9	1	0	95%
21	10	0	0	100%

For 10 cell ACC: two speed motors recommended for control purposes

When to use VFD's or 2-speed motors?

Let's set the criterion that Δ condensing capacity between 2 consecutive steps is about 5%;

Data: Δ condensing capacity between 2 steps as function of # cells, with all cells FS or HS motors

If # cells < 10 → VFD's recommended

10 $\leq$ # cells < 20 → 2-speed motors

If # cells > 20 → 1-speed motors OK

# cells	all FS	all HS	Recommended
2	50.0%	25.0%	VFD's
3	33.3%	16.7%	VFD's
4	25.0%	12.5%	VFD's
5	20.0%	10.0%	VFD's
6	16.7%	8.3%	VFD's
7	14.3%	7.1%	VFD's
8	12.5%	6.3%	VFD's
9	11.1%	5.6%	VFD's
10	10.0%	5.0%	2-speed motors
11	9.1%	4.5%	2-speed motors
12	8.3%	4.2%	2-speed motors
13	7.7%	3.8%	2-speed motors
14	7.1%	3.6%	2-speed motors
15	6.7%	3.3%	2-speed motors
16	6.3%	3.1%	2-speed motors
17	5.9%	2.9%	2-speed motors
18	5.6%	2.8%	2-speed motors
19	5.3%	2.6%	2-speed motors
20	5.0%	2.5%	1-speed motors
21	4.8%	2.4%	1-speed motors
22	4.5%	2.3%	1-speed motors
23	4.3%	2.2%	1-speed motors
24	4.2%	2.1%	1-speed motors

Combination of 1-speed & 2-speed motors

Let's look into a 3 x 4 cell ACC:

- Typically: one 2nd stage cell per street
  → there are nine 1st stage cells in total
- ACC suppliers may recommend 2-speed motors for the 2nd stage cells only

Data in the table show:

- With 9 x 1-speed + 3 x 2-speed motors
  → 24 fan control steps are possible
- Δ condensing capacity < 5 % → OK

2-speed motors (or VFD's) for 2nd stage cells are recommended in freezing climates and add significantly to the control flexibility!

STEP	# FS	# HS	# OFF	COND CAP
0	0	0	12	0.0%
1	0	1	11	4.2%
2	0	2	10	8.3%
3	0	3	9	12.5%
4	1	2	9	16.7%
5	1	3	8	20.8%
6	2	2	8	25.0%
7	2	3	7	29.2%
8	3	2	7	33.3%
9	3	3	6	37.5%
10	4	2	6	41.7%
11	4	3	5	45.8%
12	5	2	5	50.0%
13	5	3	4	54.2%
14	6	2	4	58.3%
15	6	3	3	62.5%
16	7	2	3	66.7%
17	7	3	2	70.8%
18	8	2	2	75.0%
19	8	3	1	79.2%
20	9	2	1	83.3%
21	9	3	0	87.5%
22	10	2	0	91.7%
23	11	1	0	95.8%
24	12	0	0	100.0%

Rules of step switching: general approach

GENERAL APPROACH:

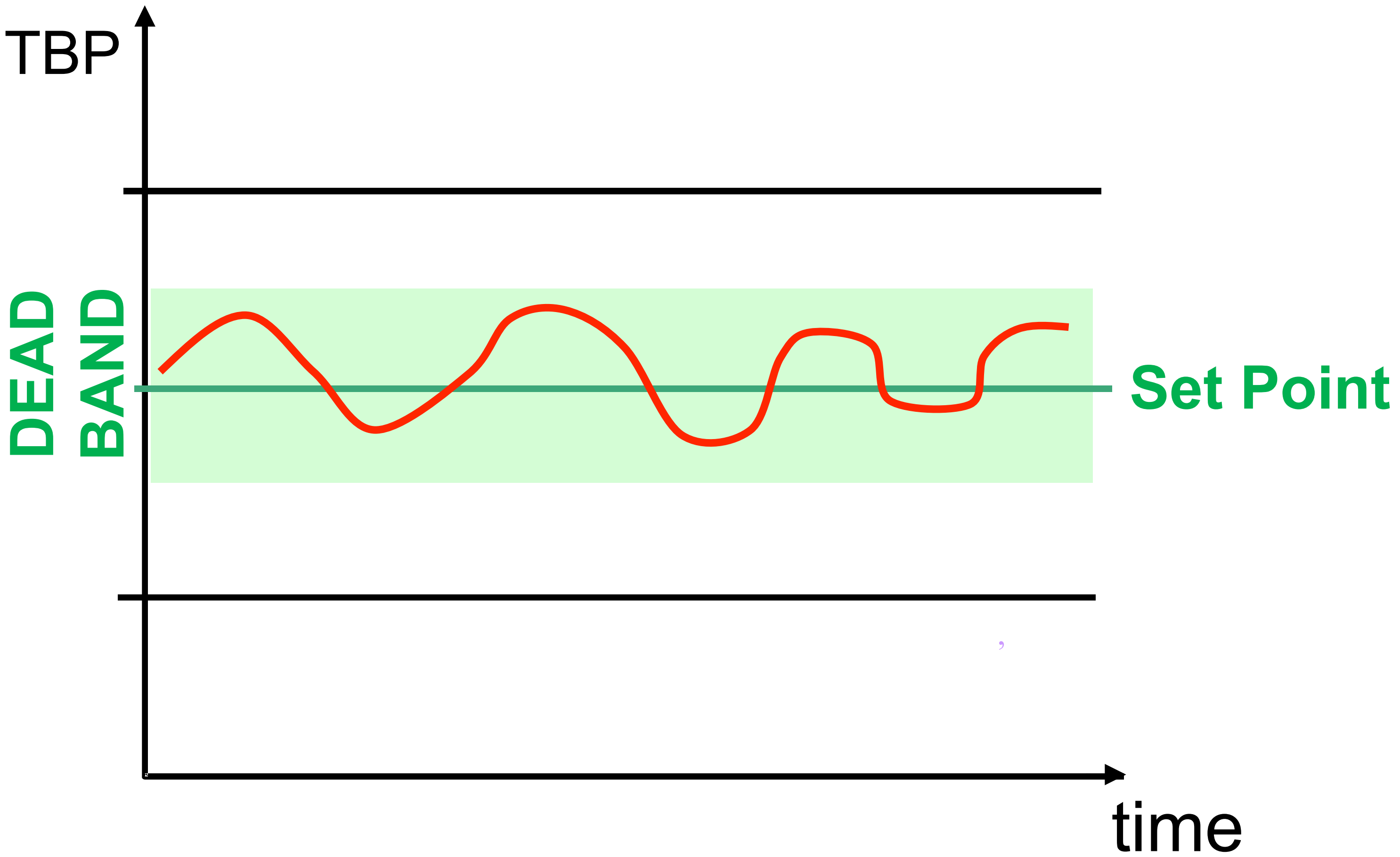
1. As long as the TBP remains in the dead band zone around the set point there is no change in condensing capacity (same fan control step);

2. If the TBP leaves the dead band, the control system will integrate the difference between the measured value & SP; if this difference reaches a certain value → this will result in a change in condensing capacity.

3. If a rapid increase/decrease in TBP occurs → this will lead to a change in condensing capacity if the measured value of TBP is too far from set point.

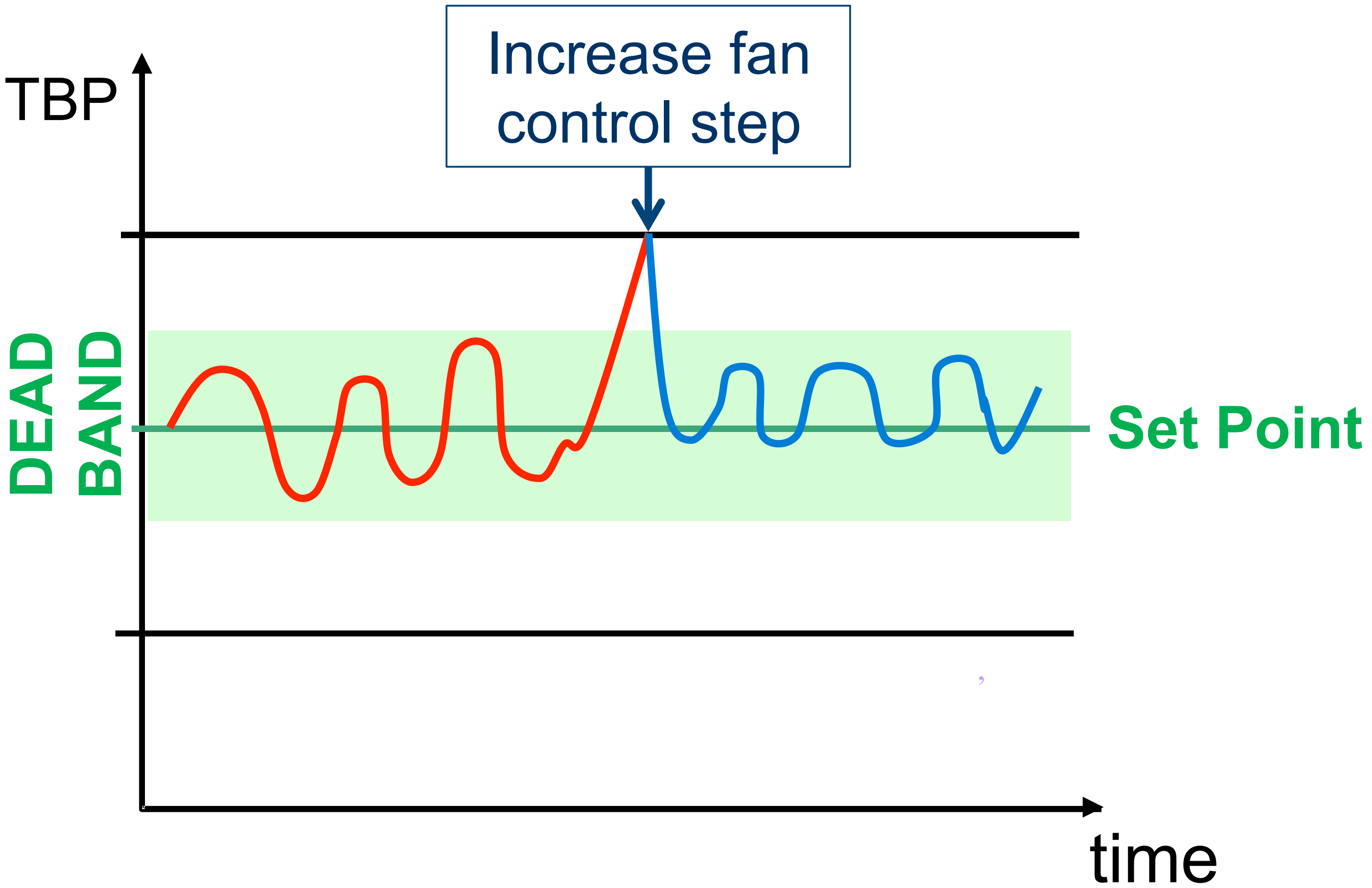
This general approach will be illustrated in the next 3 slides

Rules of step switching: TBP in dead band



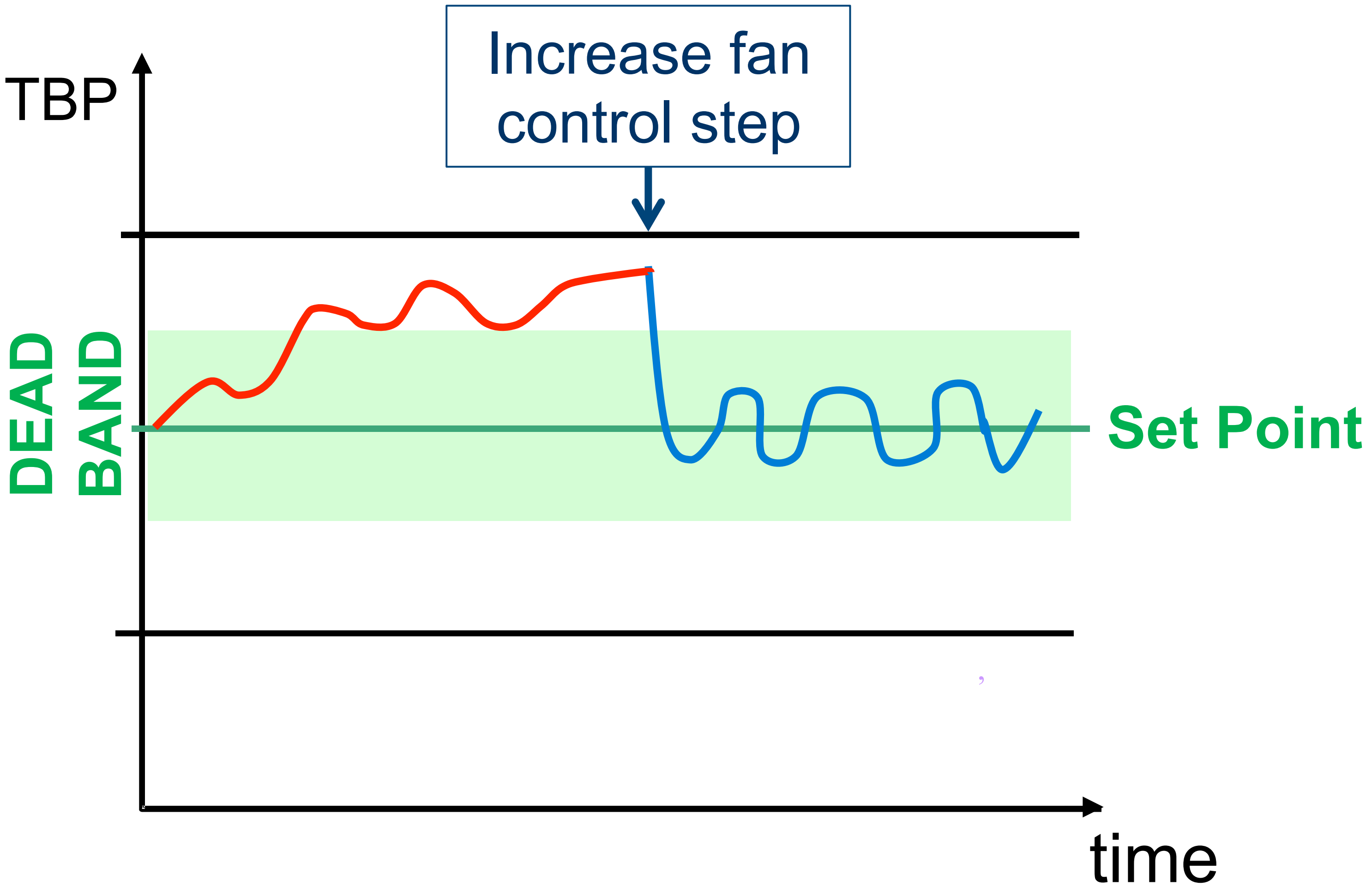
TBP stays in the dead band → no change in fan control step

Rules of step switching: rapid change in TBP



Rapid change in TBP → change in fan control step @ HIGH or LOW limit

Rules of step switching: TBP out dead band

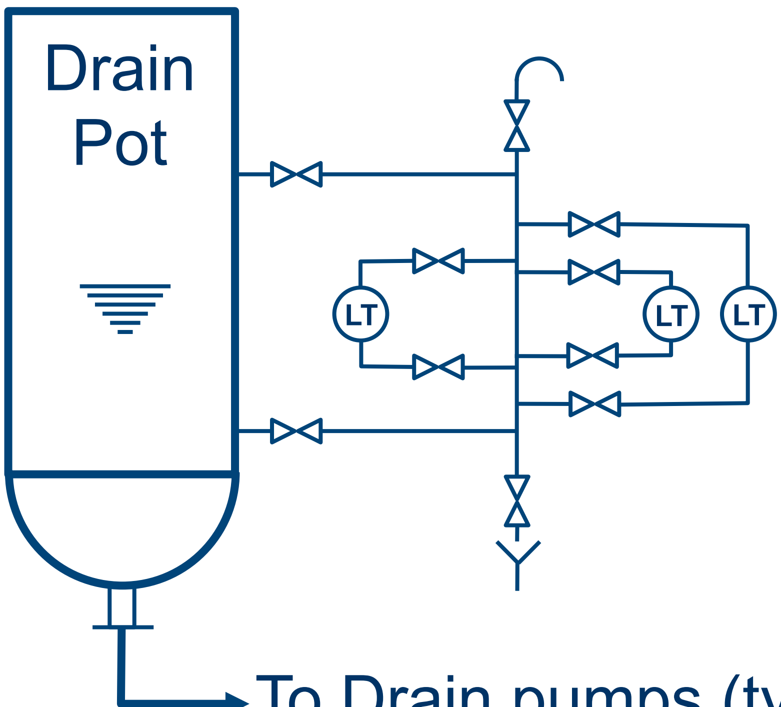


When TBP leaves dead band → step change if integrated difference is large

Drain pot level control

Typically 3 LT's are supplied for level control

→ usually acting on control valve downstream of drain pumps



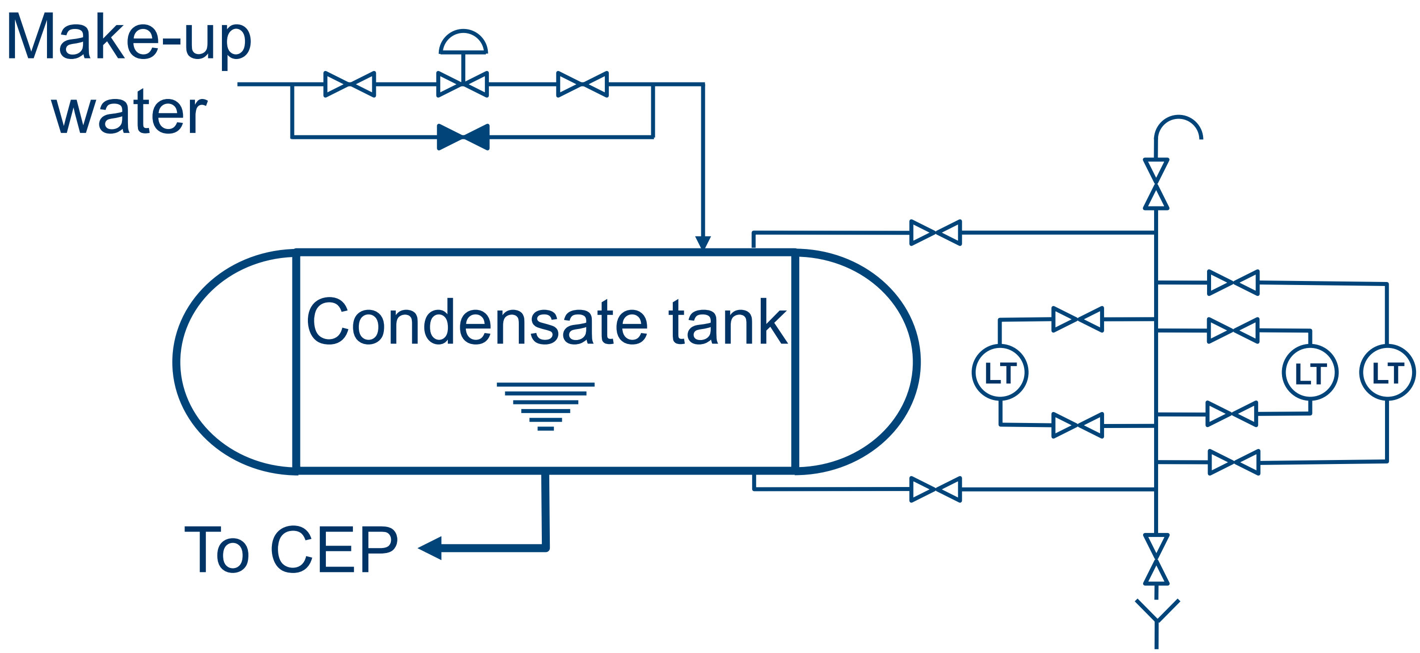
Alarms & Trips:

- HHH level: plant trip
- HH level: ALARM + start 2nd pump
- H level: start 1st pump
- L level: stop 2nd pump
- LL level: stop 1st pump
- LLL level: ALARM + forbidden to start pumps manually

To Drain pumps (typically 2 x 100% pumps)

Condensate tank level control

Typically 3 LT’s are supplier for level control
→ Usually controlling the make-up flow to the condensate tank



Alarms & Trips: similar as for drain pot; HHH level → trip of unit and LLL level → stop all condensate extraction pumps

ACC Freeze protection

ACC freeze protection considerations:

- Low steam flow to ACC & low ambient $\rightarrow$ freezing risk
- Freeze protection is activated when $T_{air} < 32°F$ (0°C)
- Condensate temperature to be kept above min level
- In freezing climates it is recommended to insulate & heat trace certain piping & equipment

Freeze protection actions:

- Enhanced monitoring of process conditions by operator
- Modification of air control (fan speed, louvers, hot box mode)
- Reduce heat transfer area @ start-up (using isolation valves)
- Increase TBP set-point if $T_{condensate} < 75°F \rightarrow T_{condensate} \nearrow$

Highest freezing risk: start-up @ below freezing temps

Typical C&I scope for ACC supplier

- Supply of all instruments for safe operation of ACC, including instrumentation required for ACC control & protection

- Important deliverables related to the ACC control:
  - P&ID
  - Functional description (write-up)
  - Fan Control steps
  - Logic Diagrams related to ACC control

Implementation of control logic and programming of the DCS → is not in the scope of the ACC suppliers.

The ACC supplier of choice:

Time for a Cool Change