INSTITUTE OF MEASUREMENT & CONTROL

Turbomachinery Controls Best Practices: Carbon Capture, Utilization and Storage (CCUS)

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Compressor Controls Corporation

What Is "Net Zero"

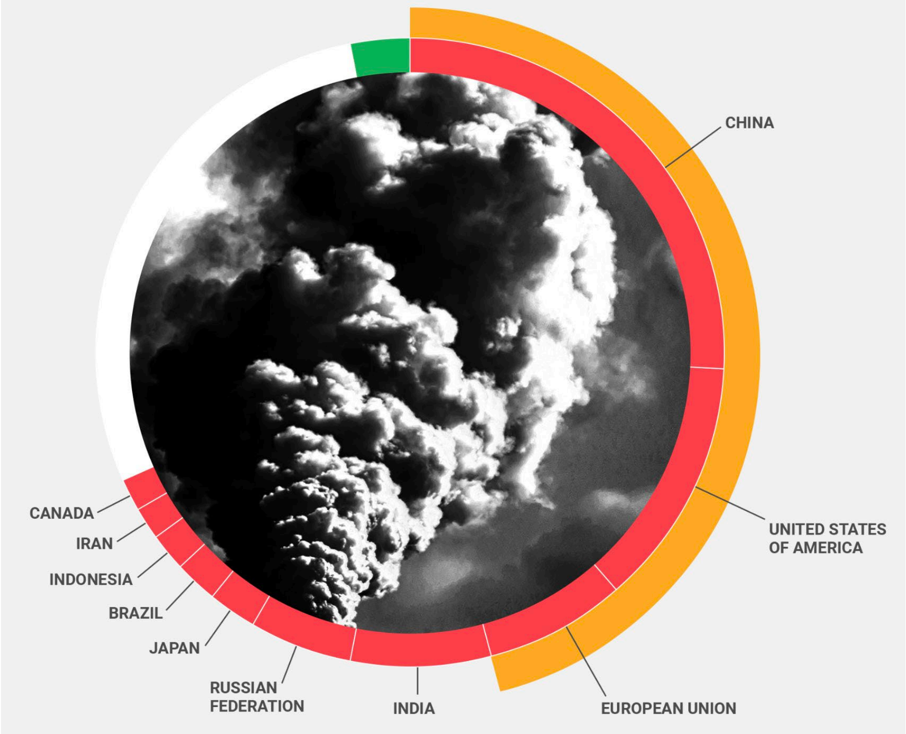
- Put simply, net zero means cutting greenhouse gas emissions to as close to zero as possible, with any remaining emissions re-absorbed from the atmosphere, by oceans and forests for instance.
- To keep global warming to no more than 1.5°C – as called for in the Paris Agreement – emissions need to be reduced by 45% by 2030 and reach net zero by 2050.
- Transitioning to a net-zero world is one of the greatest challenges humankind has faced. It calls for nothing less than a complete transformation of how we produce, consume, and move about. The energy sector is the source of around three-quarters of greenhouse gas emissions today and holds the key to averting the worst effects of climate change. Replacing polluting coal, gas and oil-fired power with energy from renewable sources, such as wind or solar, would dramatically reduce carbon emissions.
- A growing coalition of countries, cities, businesses and other institutions are pledging to get to net-zero emissions. More than 70 countries, including the biggest polluters – China, the United States, and the European Union – have set a net-zero target, covering about 76% of global emissions. Over 1,200 companies have put in place science-based targets in line with net zero, and more than 1,000 cities, over 1,000 educational institutions, and over 400 financial institutions have joined the Race to Zero, pledging to take rigorous, immediate action to halve global emissions by 2030.
- **Are we on track to reach net zero by 2050? No.**

All underlined text are clickable links

What Is "Net Zero"

- Current national climate plans – for all 193 Parties to the Paris Agreement taken together – would lead to a sizable increase of almost 14% in global greenhouse gas emissions by 2030, compared to 2010 levels. Getting to net zero requires all governments – first and foremost the biggest emitters – to significantly strengthen their Nationally Determined Contributions (NDCs) and take bold, immediate steps towards reducing emissions now. The Glasgow Climate Pact called on all countries to revisit and strengthen the 2030 targets in their NDCs by the end of 2022, to align with the Paris Agreement temperature goal.

  - **3%** Contribution of the 100 least-emitting countries
  - **68%** The 10 largest greenhouse gas emitters contribute over two-thirds of global emissions
  - **46%** The top 3 greenhouse gas emitters contribute 16 times the emissions of the bottom 100 countries



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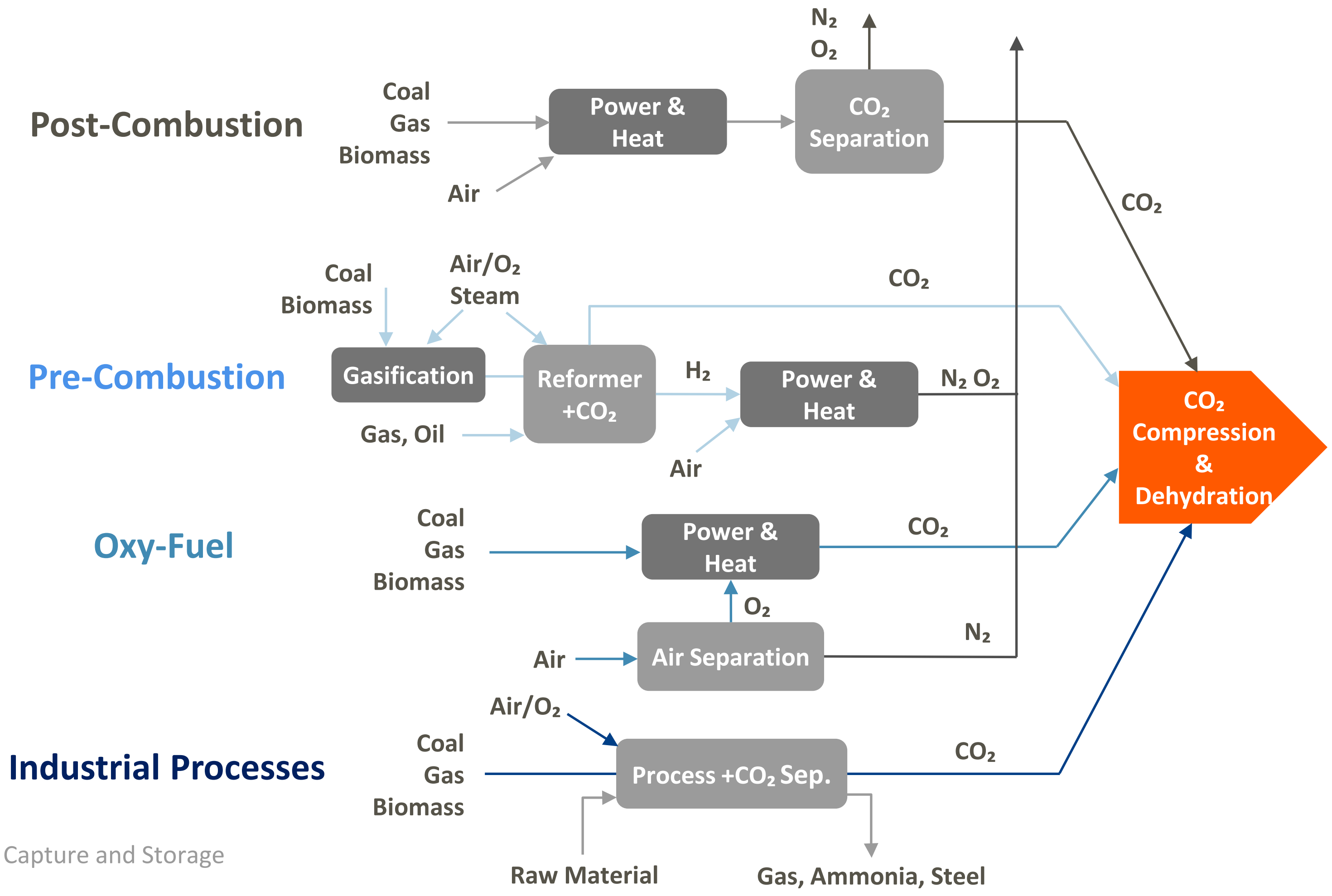
What Is “Net Zero”

The Intergovernmental Panel on Climate Change (IPCC) is the UN body for assessing the science related to climate change. It recognizes four sources of CO_2 emissions, for large source points:

- Post-combustion of flue gasses produced by combustion of fossil fuels or bio-mass.
- Pre-combustion.
- Oxy-Fuels.
- Capture From Industrial Process Streams (e.g. Natural Gas purification, Cement, Steel, Ammonia).

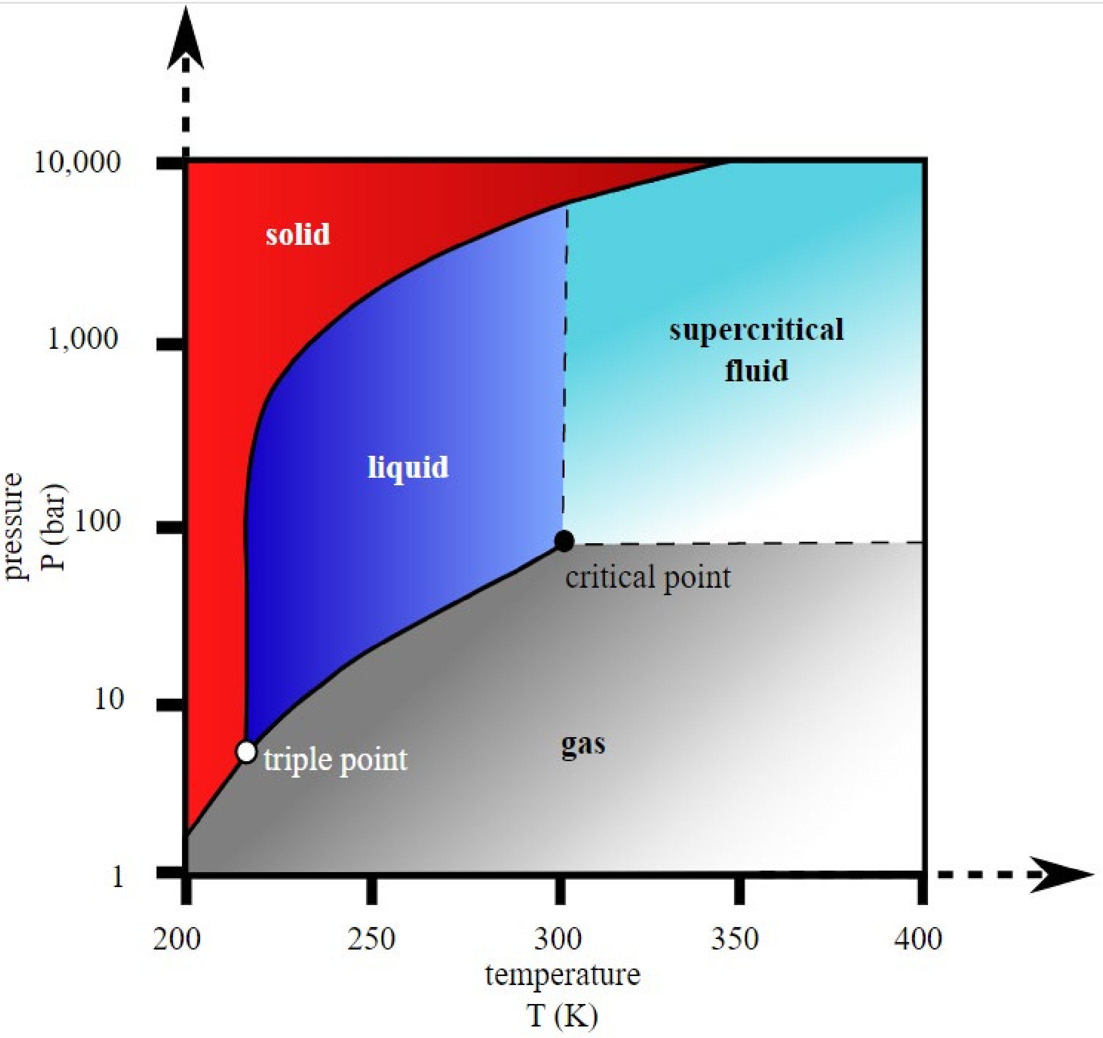


Source: IPCC Special Report on Carbon Dioxide Capture and Storage

CO_2 Capturing and Compression Overview

Why Compress CO2

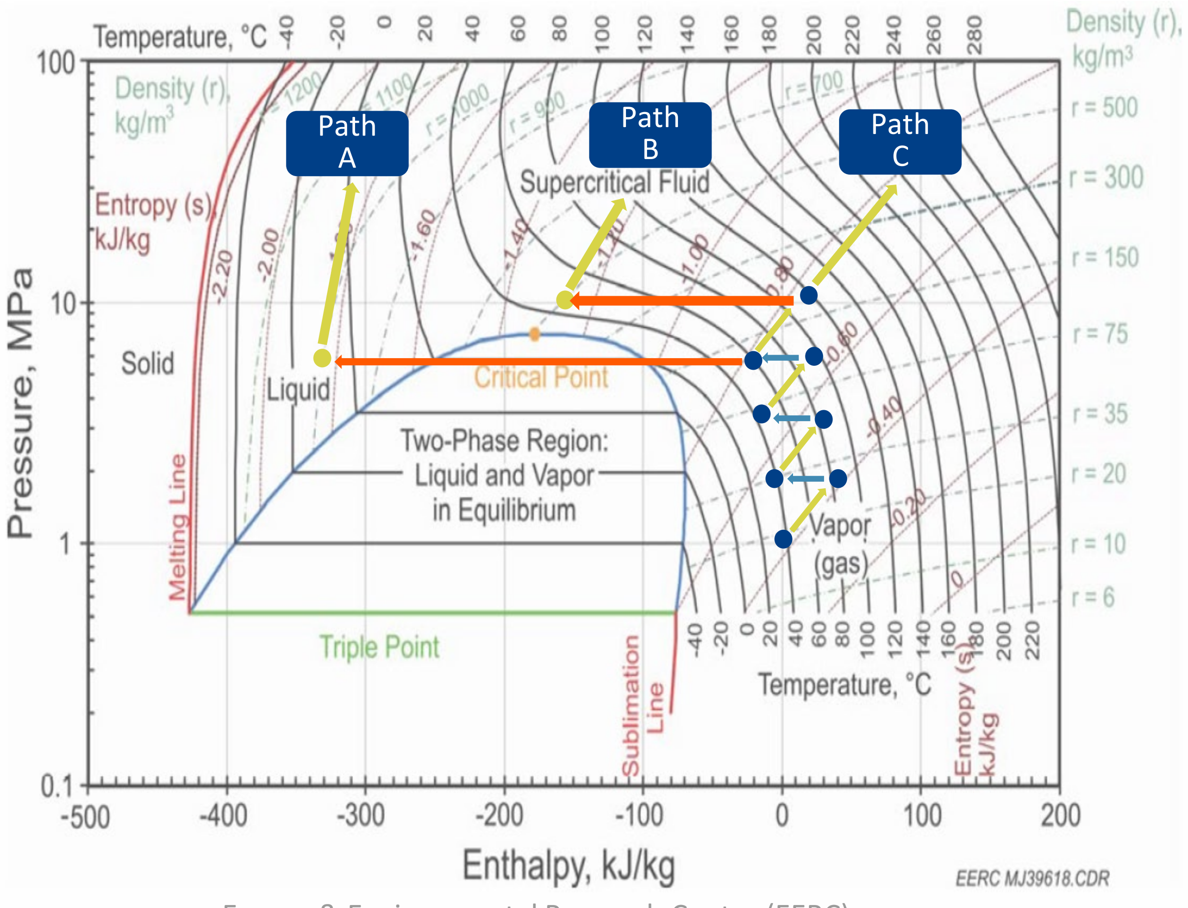
- CO_2 is typically compressed to minimize volume and pressurized enough to overcome the reservoir pressure.
- Therefore, the pressure needed depends on storage location
- Typically, CO_2 is transported in its supercritical fluid state, where it exhibits characteristics of both a vapor (gas) and a liquid.



Source: Wikipedia

CO_2 Compression Approaches

- Path A (Produces Liquid CO_2): Utilizes fewer compression stages with interstage cooling, then cools CO_2 to form a liquid and pumps it to the desired final pressure.
- Path B (Produces "Dense-Phase" Supercritical CO_2): Utilizes more compression stages with interstage cooling until pressure is above critical point. CO_2 is then cooled to a more dense-phase supercritical fluid and pumped to its final pressure.
- Path C (Produces "Gaseous" Supercritical CO_2): multiple stage compression with interstage cooling in the vapor/supercritical condition. Either "hot" CO_2 is sent directly to the pipeline (where it is cooled by the environment) or it is after-cooled by a heat exchanger to a lower temperature (e.g. 30 ~ 40 degC).



Energy & Environmental Research Center (EERC)

Compression
Inter-Stage Cooling
Condensing / Recooling to High Density

CO2 Compressor Types

Reciprocating compressors:

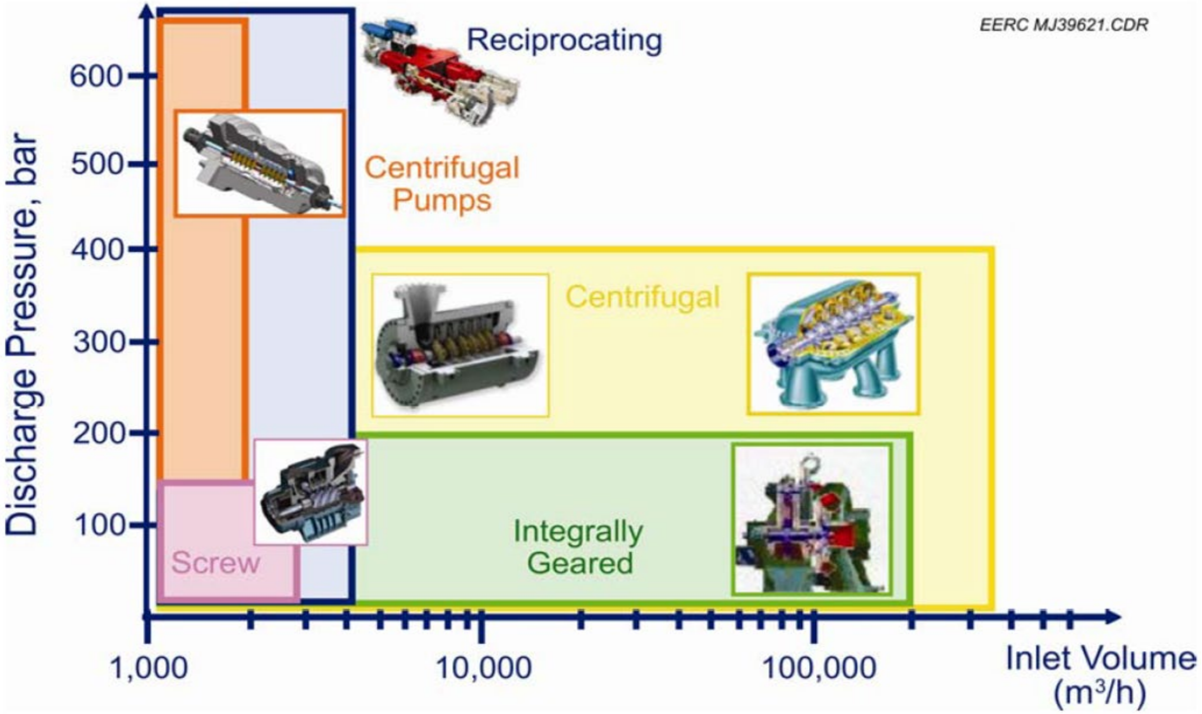
- Used for high pressure application
- Inlet flow rates are limited
- The capacity may be below that of captured CO_2 streams
- Reciprocating compressors are maintenance-intensive and high in capital and operating costs
- Centrifugal compressors:
- Commonly used for high-capacity CO_2 compression.

In-line centrifugal compressors

- Offers high efficiency, oil-free compression, and high speed matched to high-speed drivers. Considered less maintenance intensive.

Integrally geared centrifugal compressors

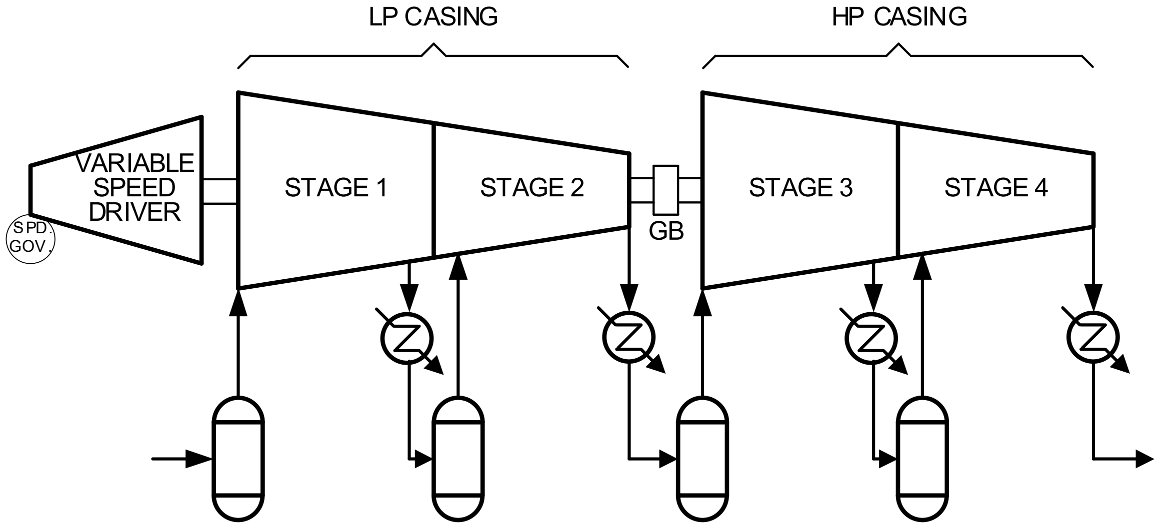
- Offers high efficiency and is more flexible in stage design
- Limited to discharge pressures below 200~250bar



Energy & Environmental Research Center (EERC)

Typical In-Line CO_2 Centrifugal Compressor

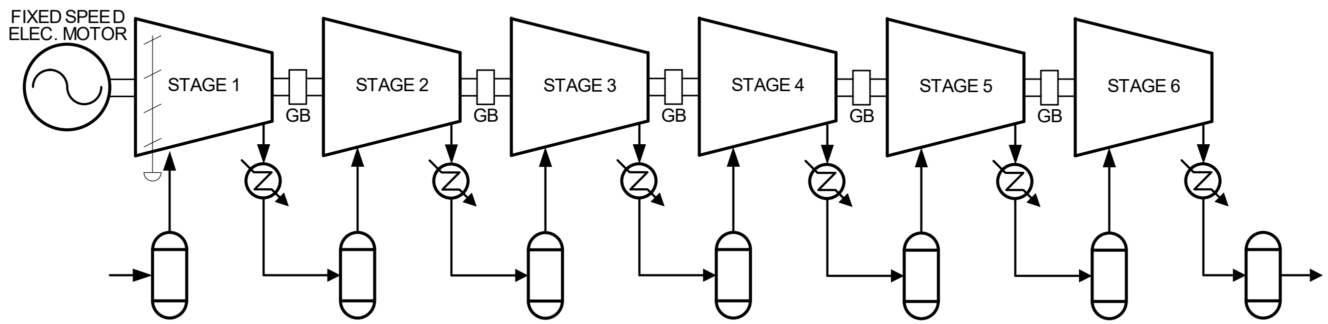
- Variable speed drive compressors
- Typical two casings (LP & HP) with intercoolers
- Each casing having 2 sections/stages
- Compressor OEMs usually provide performance curves for each section/stage
- May also provide overall performance curves for each casing



Typical Integrally-Geared CO_2 Centrifugal Compressor

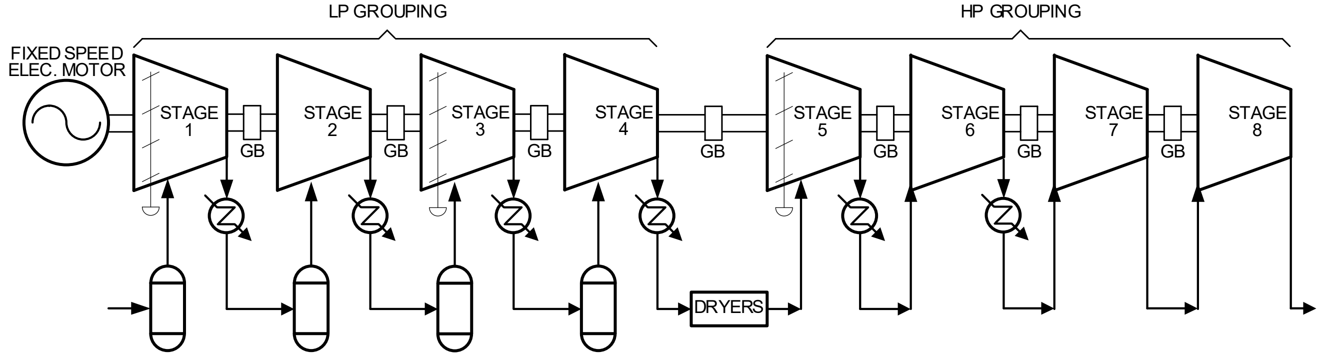
Example 1:

- 6-Section Fixed Speed drive compressors
- IGVs only on the 1st Section, requiring one single Performance Controller
- Inter- and After-cooling
- Compressor OEMs usually provide overall performance curves for whole train



Example 2:

- 8-Section Fixed Speed drive compressors
- IGVs on the 1st, 3rd and 5th Sections, requiring 3 Performance Controllers.
- Inter- and After-cooling only for the first 6 stages.
- Compressor OEMs usually provide overall performance curves for LP & HP Grouping.



Major Process & Operation Challenges of In-Line CO_2 Compression

Typical In-Line CO_2 Centrifugal Compressor

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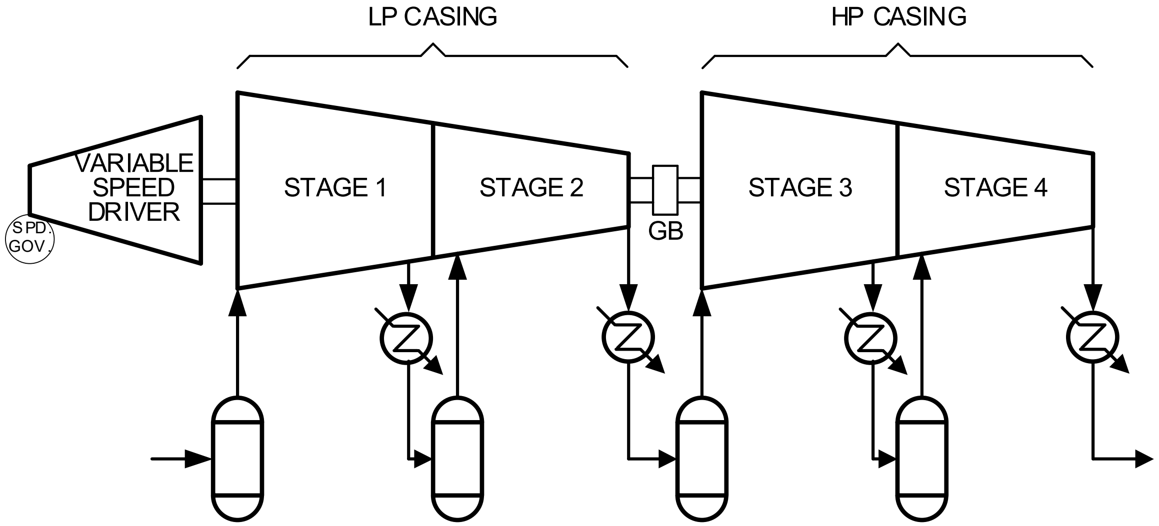


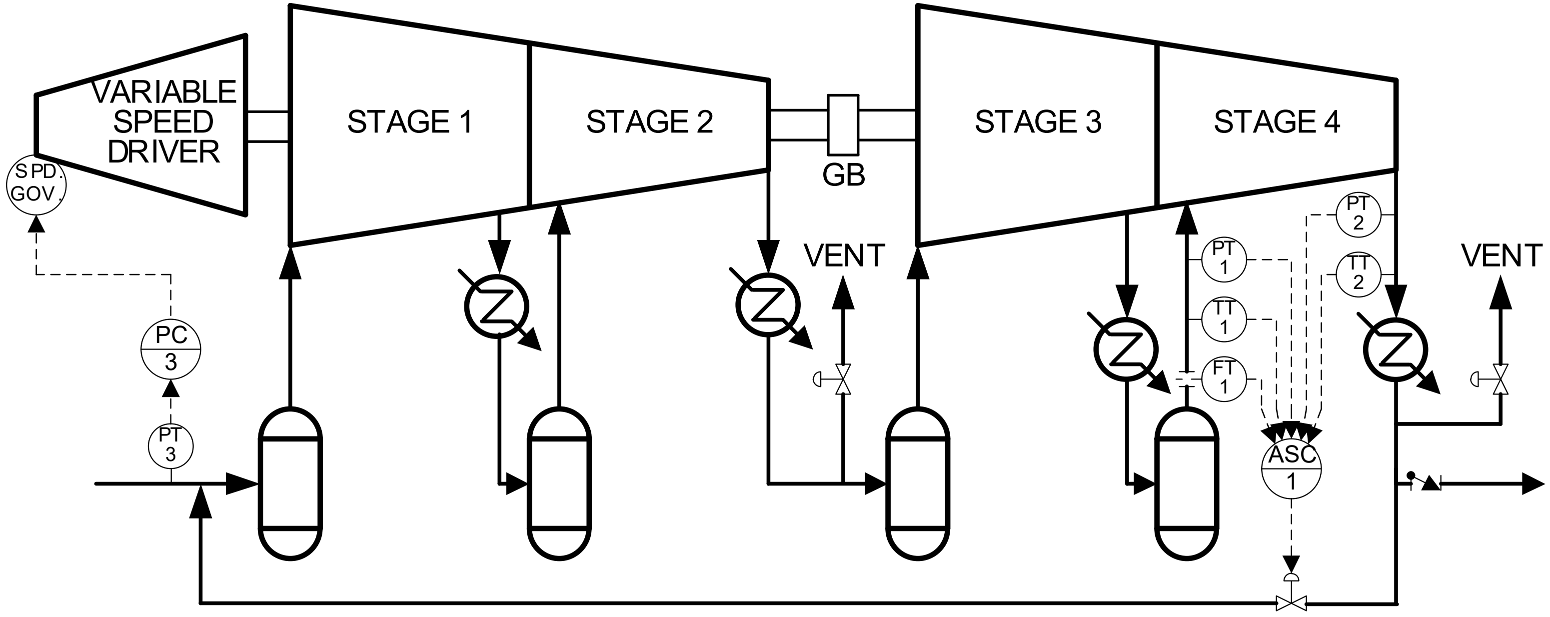
Major Process & Operation Challenges of CO_2 Compression: Summary

- High compressor discharge pressure and the resultant wide variations in gas properties create challenges to compressor design & operations
- Compressor stage "mismatch"
- Unplanned process shutdown, causing CO_2 venting, financial penalty, negative publicity and potential production loss in other units
- Compressor or inter-stage cooler fouling
- CO_2 venting and process instability (suction pressure-vent hunting) during process upsets
- Recycle valve freezing

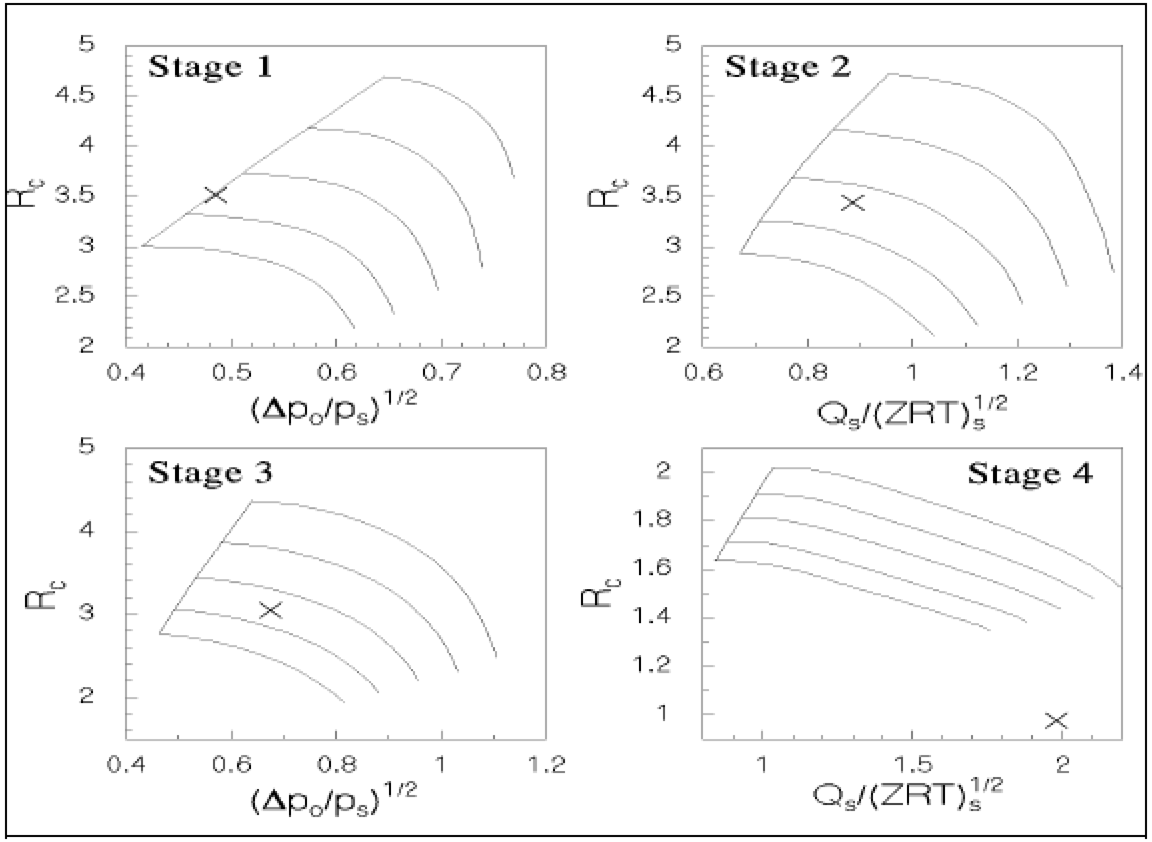
- Risks and challenges related to inadequate control of CO_2 compressor:
- Unstable or slow reacting control causing fluctuations to upstream and downstream equipment and to dehydration system
- Can't reinject all the CO_2 produced because of poor control/excess recycling
- Trips will affect upstream equipment and may cause major disturbances for the entire CO_2 capture process
- Surging in high-pressure compressors can lead to machine damage and prolonged outage

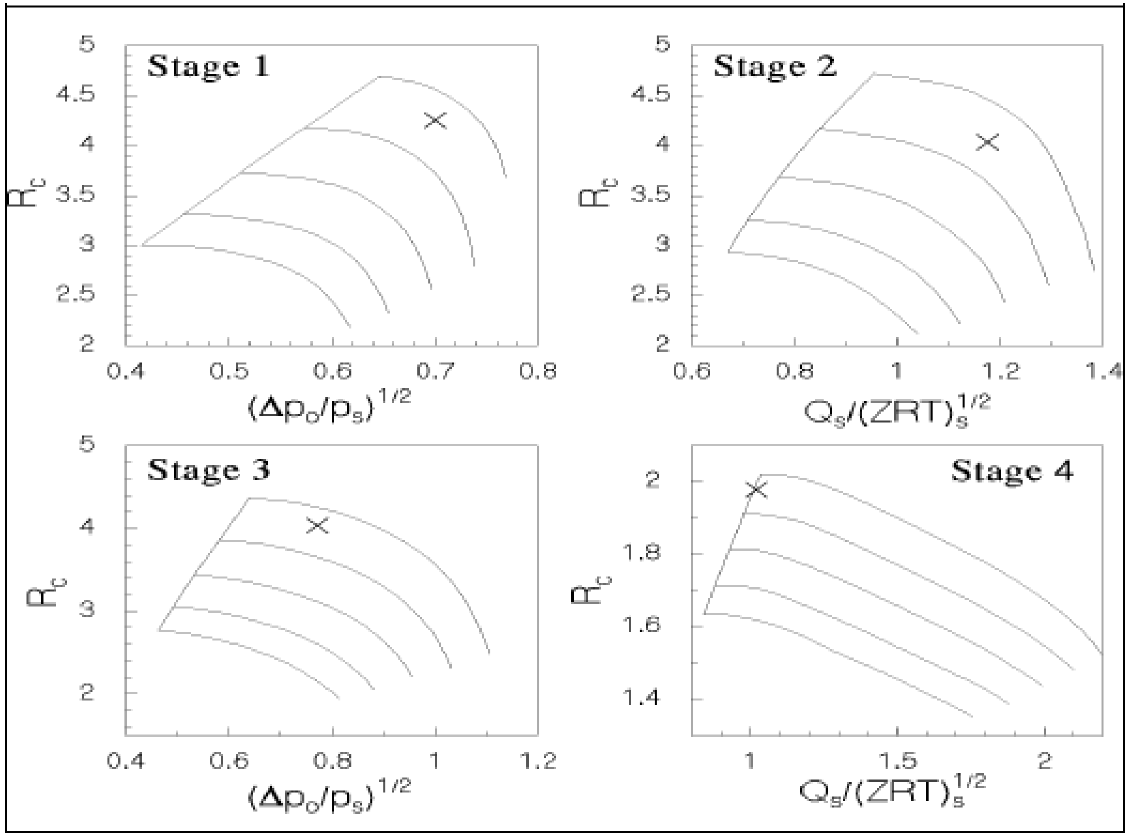
In-Line CO_2 Compressor Configuration Challenges – Early Traditional Control Design

- Single overall recycle loop and antisurge control
- Valve freezing is an issue
- Antisurge control on the stage that is expected to surge first
- Large control margins
- Venting part of the operation
- Fouling of intercoolers can cause issues with control
- This design is not recommended



In-Line CO_2 Compressor Configuration Challenges – Stage Mismatch

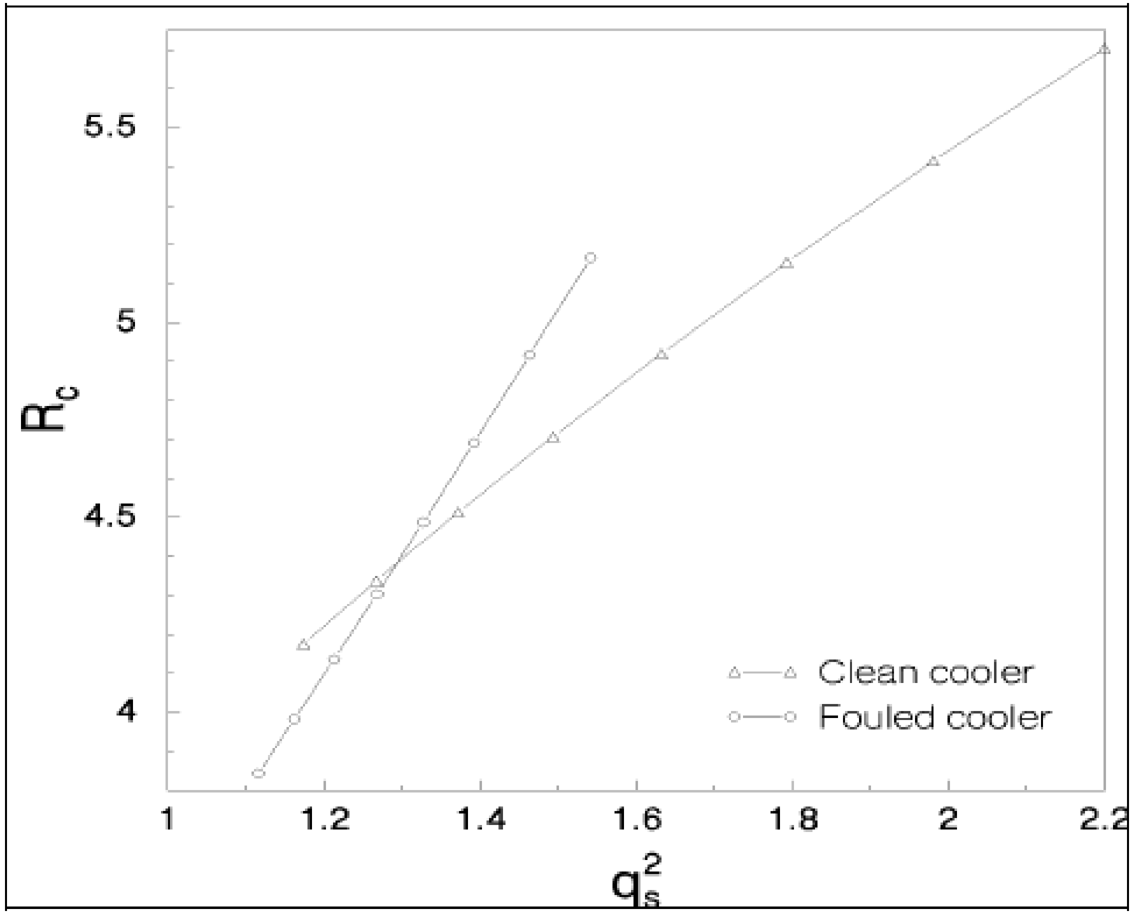




- Operating at moderate to low speeds, the 4th Section may choke while the 1st Section surges.
- Operating at higher speeds, the 4th Section surges, whereas other Sections are entirely safe.

In-Line CO_2 Compressor Configuration Challenges – Cooler Fouling

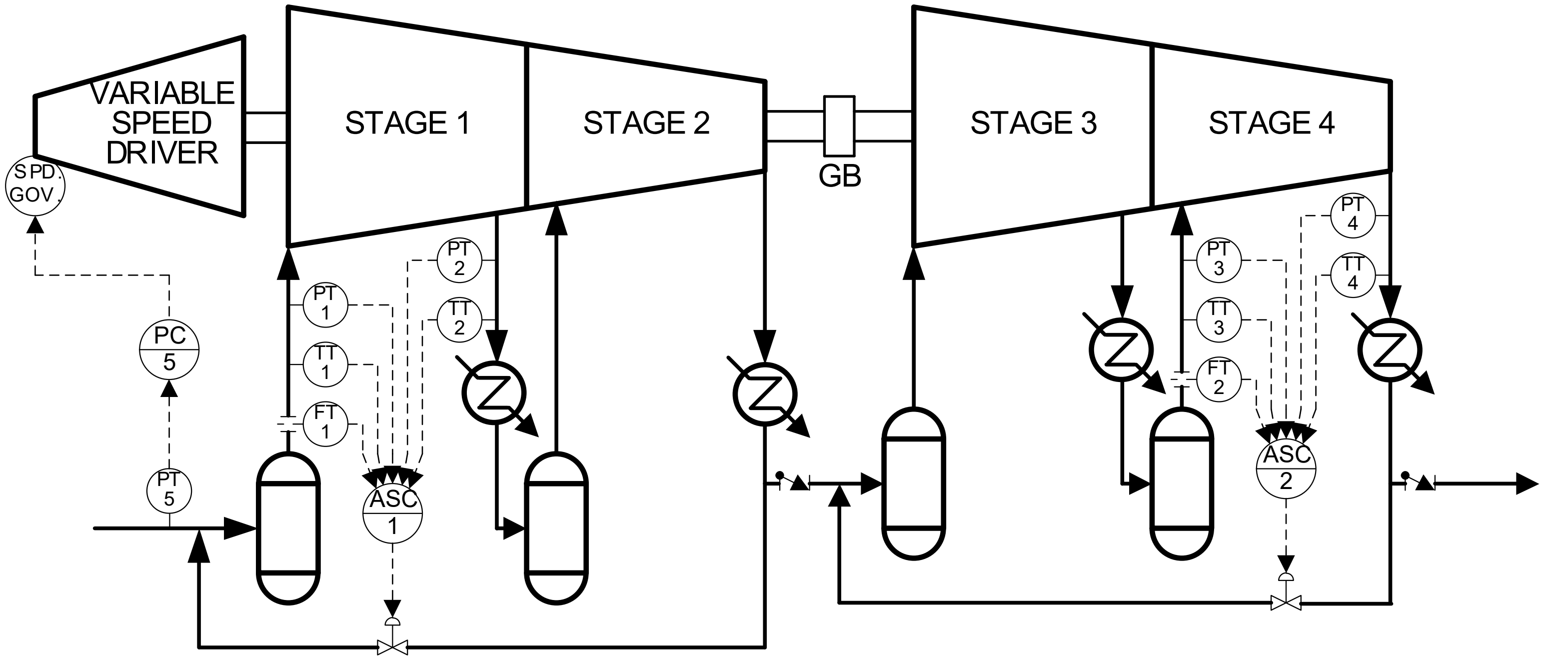
- Fouling of an interstage cooler results in an increase in temperature in the downstream compressor stage
- The surge line will shift for that stage
- May also change which stage surges first
- This shift is unaccounted for by the antisurge control system



Shift of the surge limit line due to variation in intercooling. The compressor which surges first changes with the fouling of the cooler

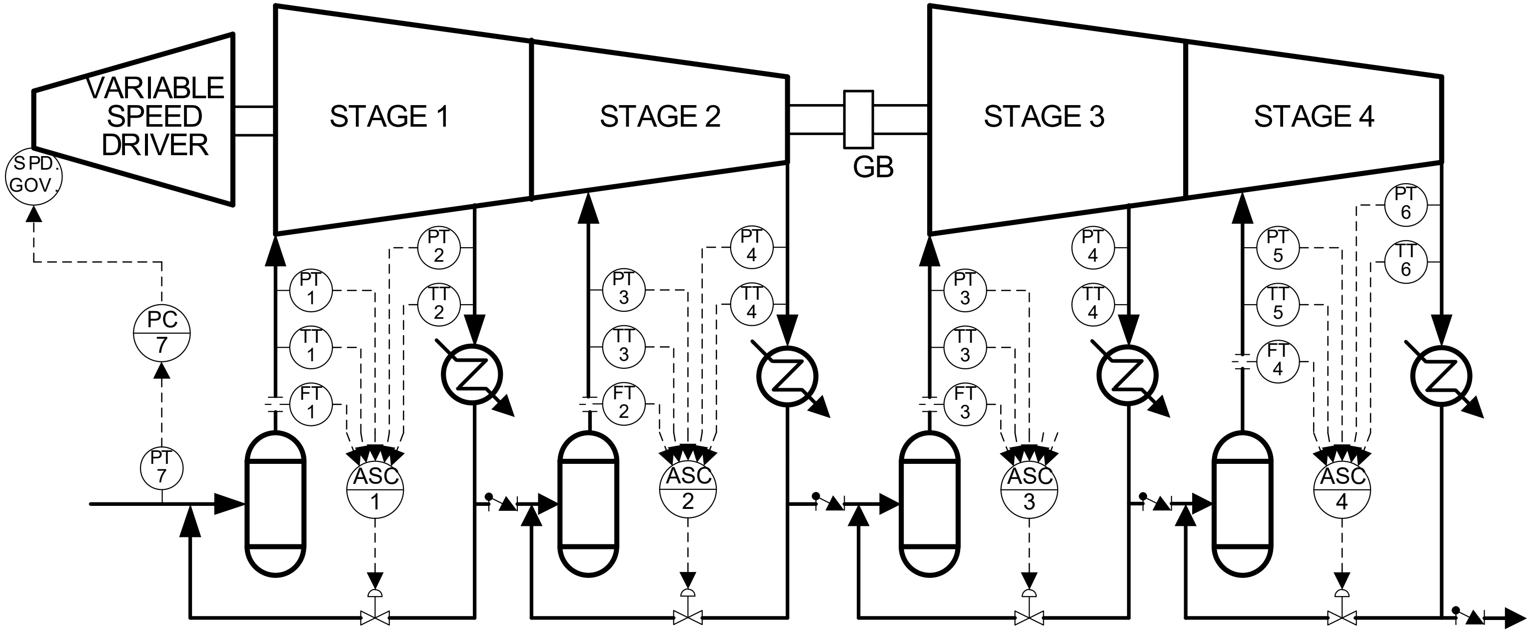
In-Line CO_2 Compressor Configuration Challenges – Improved Control Design

- Recycle loop and antisurge control for each casing
- Antisurge control on the stage that is expected to surge first for each casing
- Reduces the possibility of valve freezing
- Fouling of intercoolers can cause still issues with control
- Need for venting is reduced



In-Line CO_2 Compressor Configuration Challenges – Ideal Control Design

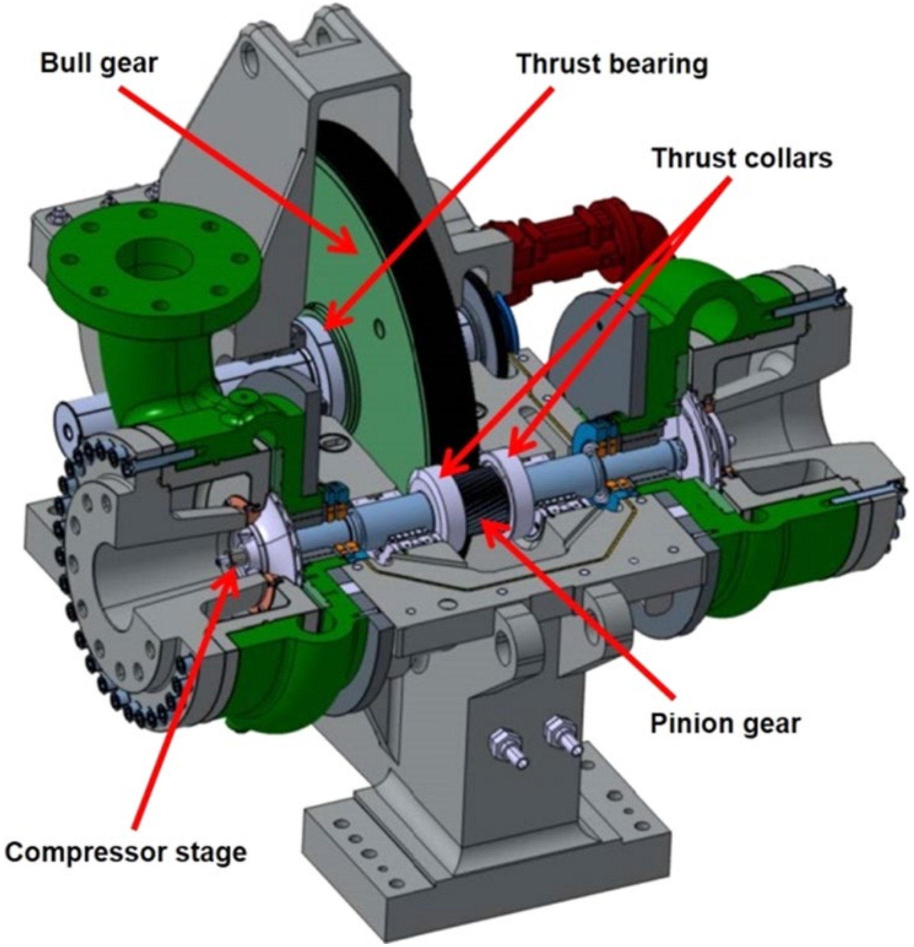
- Recycle loop and antisurge control for each Section
- Reduced Surge Control Margins possible
- Eliminates the possibility of valve freezing
- Fouling of intercoolers has no effect on Surge Control
- Venting should be eliminated



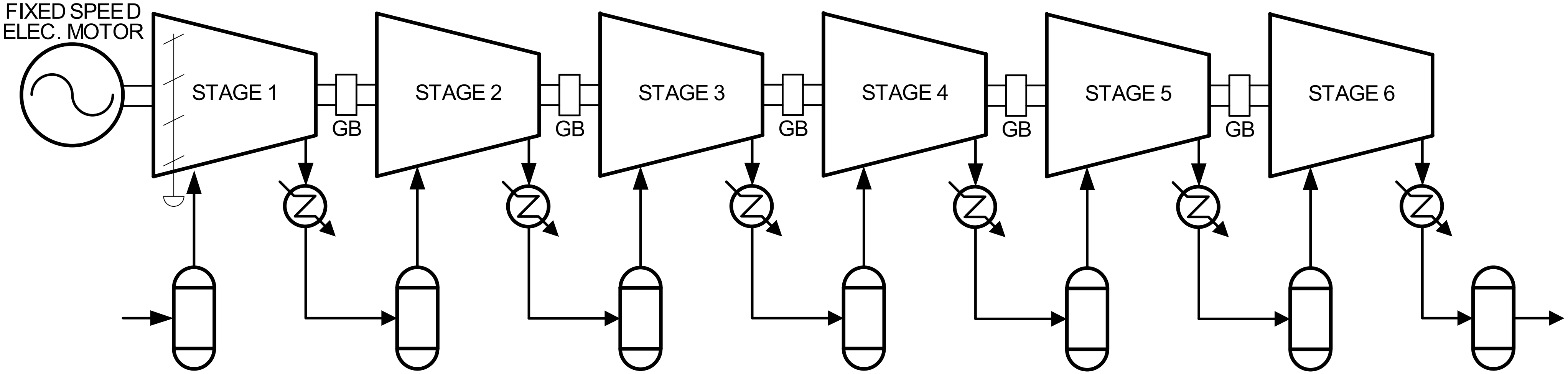
Major Process & Operation Challenges of Integrally Geared CO_2 Compression

Integrally Geared CO_2 Compressor Advantages

- Generally, this type of compressor allows a large number of stages to operate off a Bull gear, driven by a single speed driver, with an individual pinion per stage.
- It is therefore possible to precisely select the optimum speed of each stage so that all stages match perfectly with each other.
- The large number of stages (6 to 8 stages), compared to 4 stages for an equivalent Centrifugal allows for a lower pressure ratio per stage and hence the temperature rise per stage is lower.



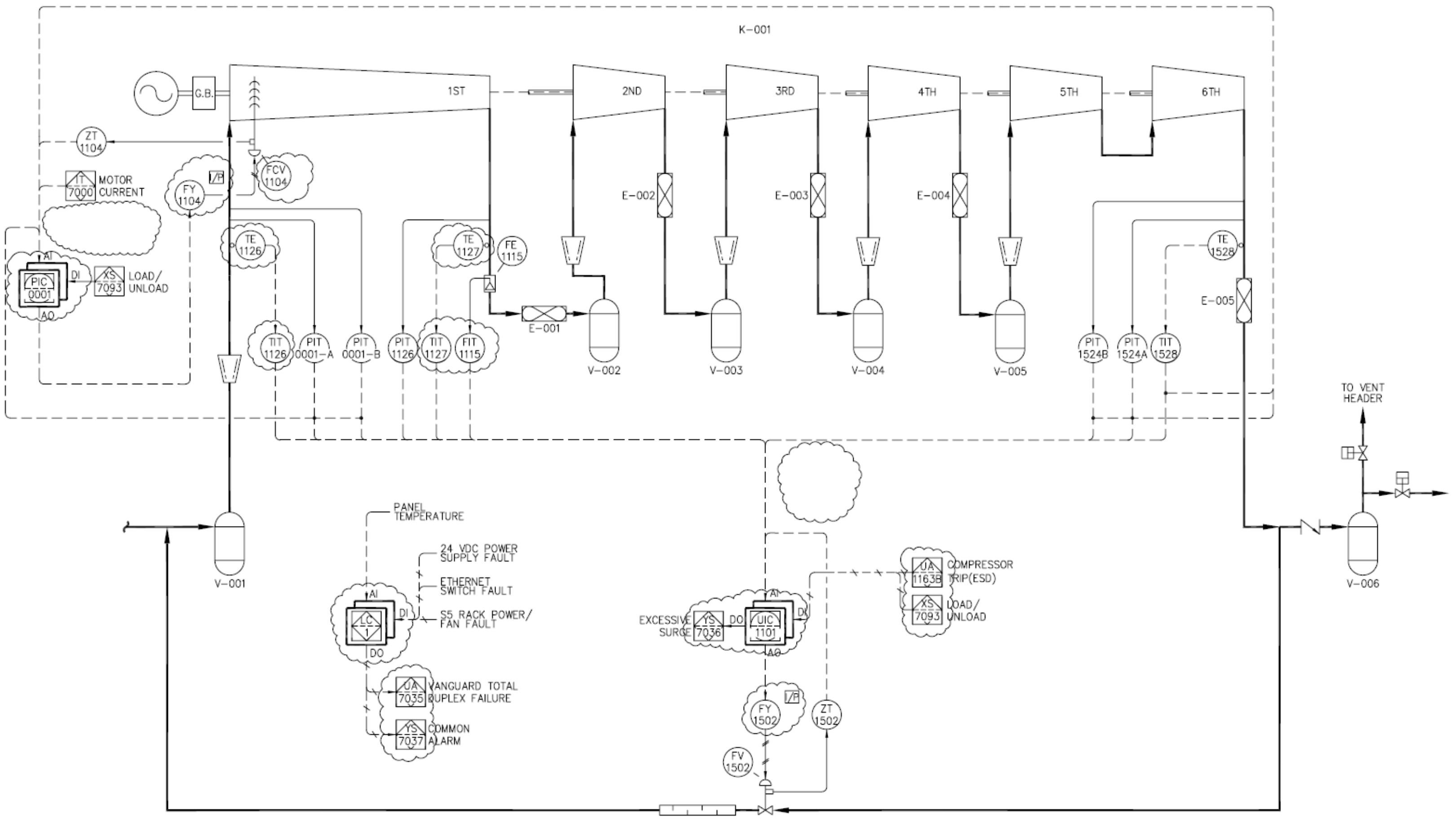
6-Stage Typical Integrally Geared CO_2 Compressor



- The ability to precisely match the characteristics of all the stages allows for one overall recycle path and hence it is possible to provide adequate surge protection with one Antisurge Controller, using the overall performance curves as the basis of design.
- In lower discharge pressure applications, say less than the critical point of CO2, or 73,8 bara at 31.0 degC, the pressure drop usually does NOT produce a Joules-Thompson temperature drop across the recycle valve that causes freezing of the valve.

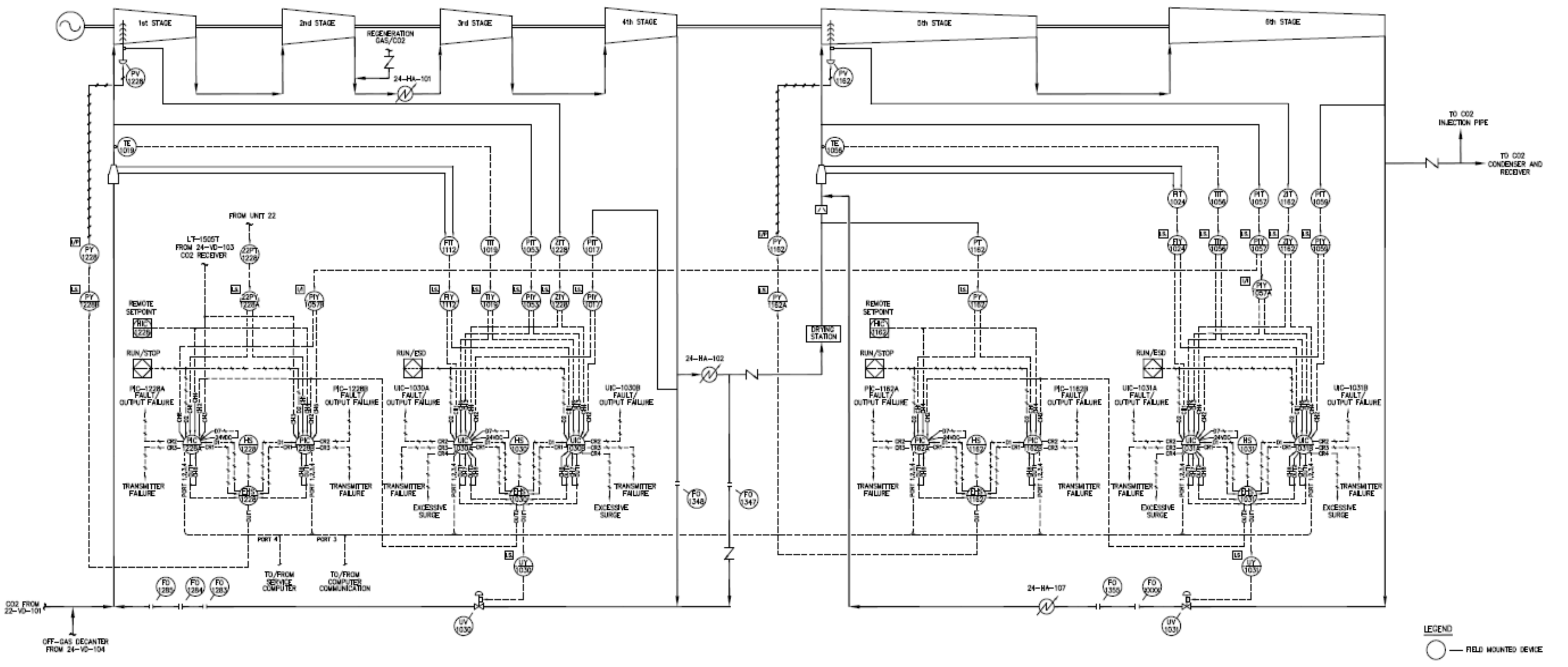
Example of 6-Stage Typical Integrally Geared CO_2 Compressor

- Single overall recycle loop and antisurge control.
- Valve freezing is an issue.
- Performance Control implemented with single IGVs on 1st Stage.
- Fouling of intercoolers can cause issues with control.

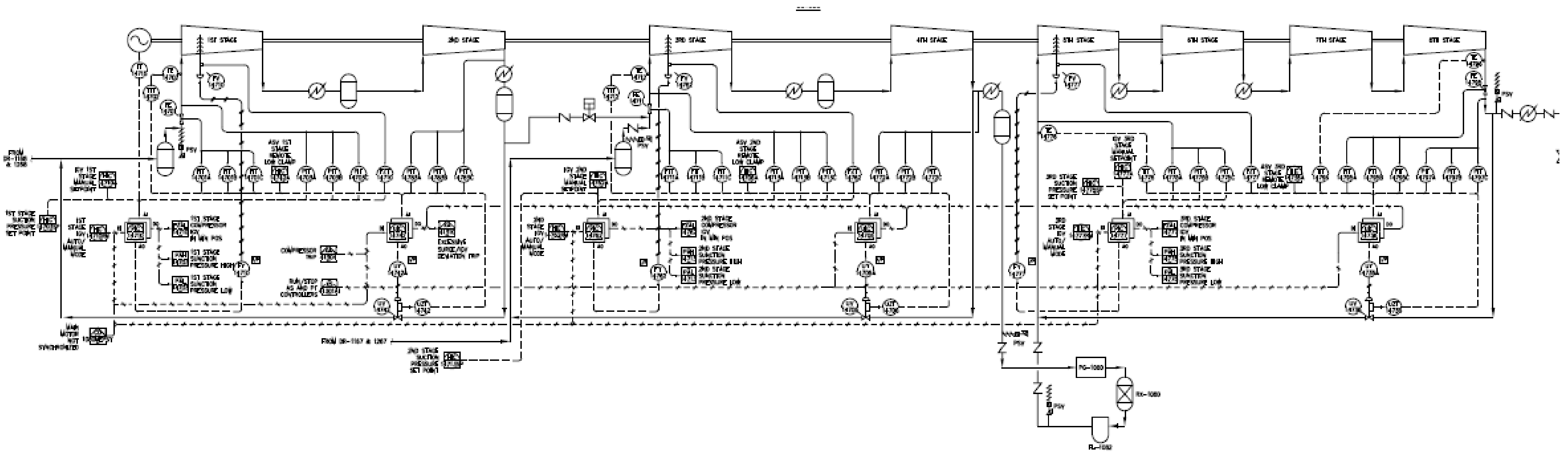


Another Example of 6-Stage Typical Integrally Geared CO_2 Compressor

- Here, there is a process drier between stages 4 and 5, so two recycle loops and 2 Antisurge Controllers are used.
- The 6-stage train is divided to LP and HP groups, with the drier in between.
- Performance Control implemented with one set of IGVs per group (on 1st Stage, and 5th Stage)
- Fouling of intercoolers can cause issues with control.



An Example of an 8-Stage Integrally Geared CO_2 Compressor



- Here, there is a 2nd incoming stream between stages 2 and 3, AND a process drier between stages 4 and 5, so three recycle loops and 3 Antisurge Controllers are used.
- The 8-stage train is divided to LP, MP and HP groups.
- Performance Control implemented with one sets of IGVs per group (on 1st Stage, 3rd Stage and 5th Stage)
- Fouling of intercoolers can cause issues with control.

CO_2 Compression Integrated Turbomachinery Controls Best Practices

Integrated Turbomachinery Controls vs. Traditional Controls

- Traditional turbomachinery controls usually have independent control loops for surge control and for capacity (Performance) control.
- These independent control loops may be in the DCS or may be supplied by the compressor OEM. Usually they are considered “integrated” when residing on the same hardware platform, but this is not true integration.
- Advanced turbomachinery controls, on the other hand, are designed with the surge and compressor capacity control loops communicating with each other in a truly integrated manner (even if they physically reside on separate hardware “boxes”). The integrated loops continuously exchange data, such as:

Antisurge Controller Broadcasts

- Proximity-to-Surge Variable Value
- Operating State (Run, Stop, Tracking, etc.)
- Output Value
- Open Loop (RT) Event
- P-Action & I-Action Values
- Limit Loop Active
- Auto/Manual State
- Decoupling Variable Value

Performance Controller Broadcasts

- Set-Point Values
- Operating State (Run, Stop, Tracking, etc.)
- Output Value
- Limit Loop Active
- Auto/Manual State
- Local/Remote State
- Decoupling Variable Value

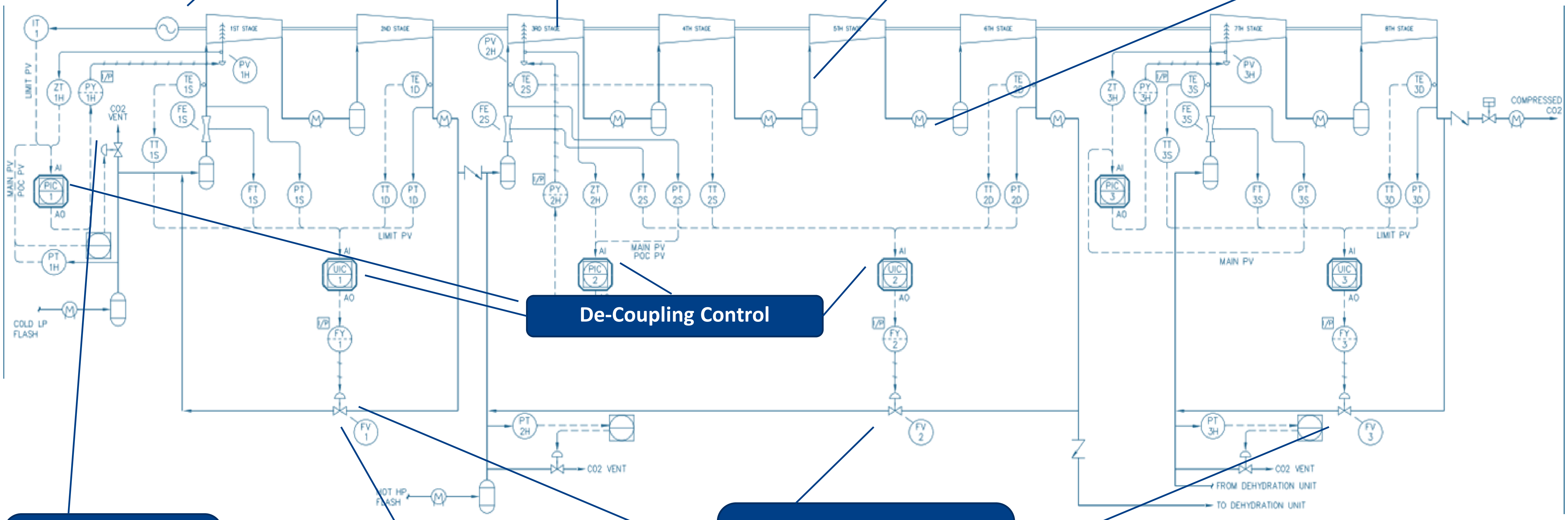
CO_2 Compressor Integrated Turbomachinery Control

Motor Current Limit

Performance Control & Stage Mismatching Avoidance

Pipeline Design and Energy Optimization Consultation

Intercooler Fouling Detection (CPA)



De-Coupling Control

Reduce Venting with tight Pressure Control

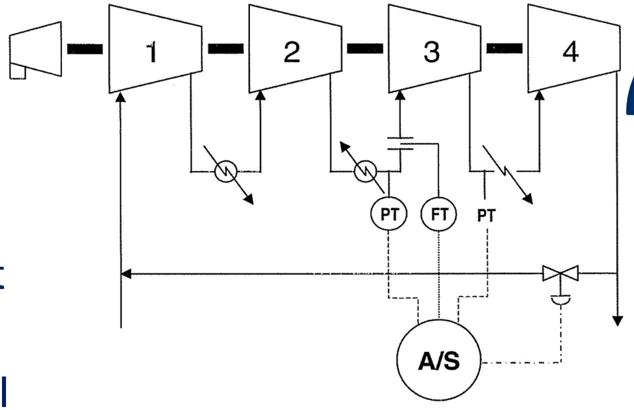
Antisurge control w/process limiting

Recycle Valves sizing, Valve Sharing and Valve Usage for Capacity Control

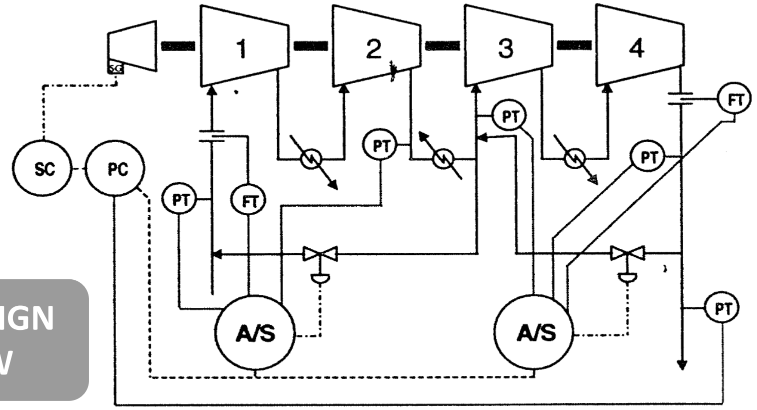
Engineering Design Services for Pre-FEED and FEED

CCC expertise deployed early enough during initial design to:

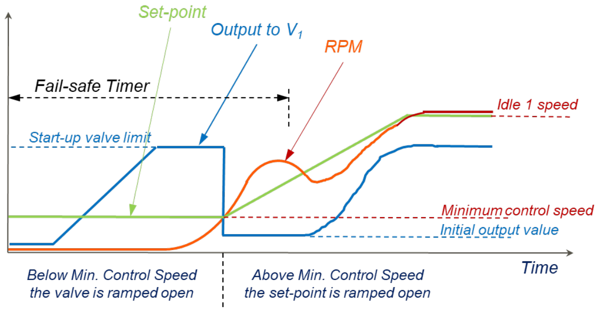
- Reduce risk and change management costs on projects
- Increase project design quality, control and consistency across multiple OEMs
- Support conceptual design for turbomachinery in new processes
- Use CCC Emulator with multi-purpose dynamic simulators to validate design



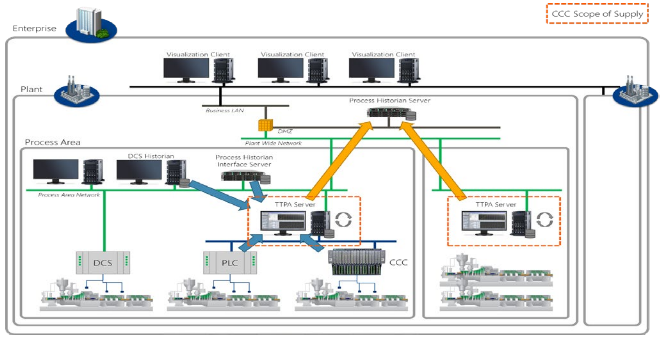
Avoid Recycle valve freezing and compressor stage mismatch



P&ID DESIGN REVIEW



SEQUENCING



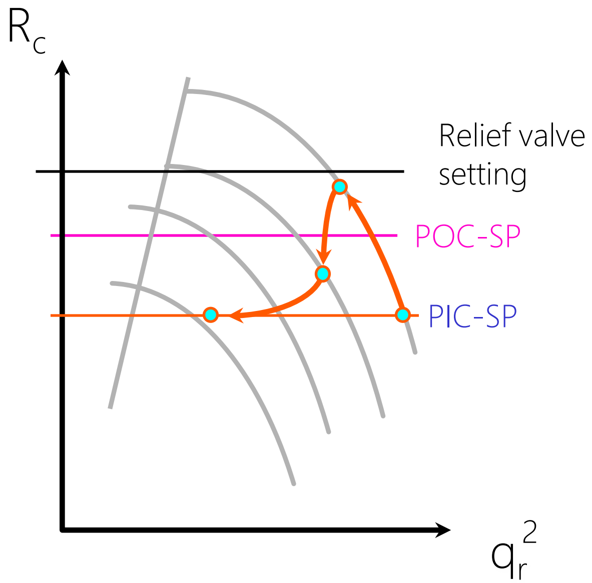
CYBERSECURITY

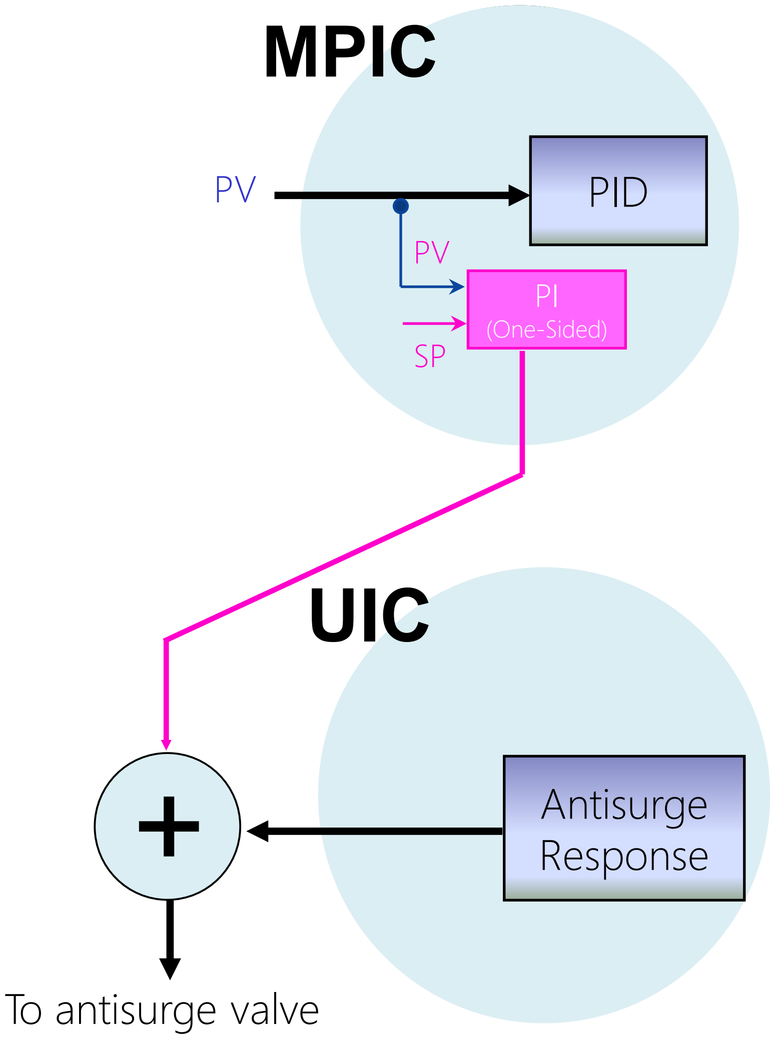
DIGITALIZATION

INSTRUMENTATION SELECTION GUIDELINES

Performance Override Control (POC)

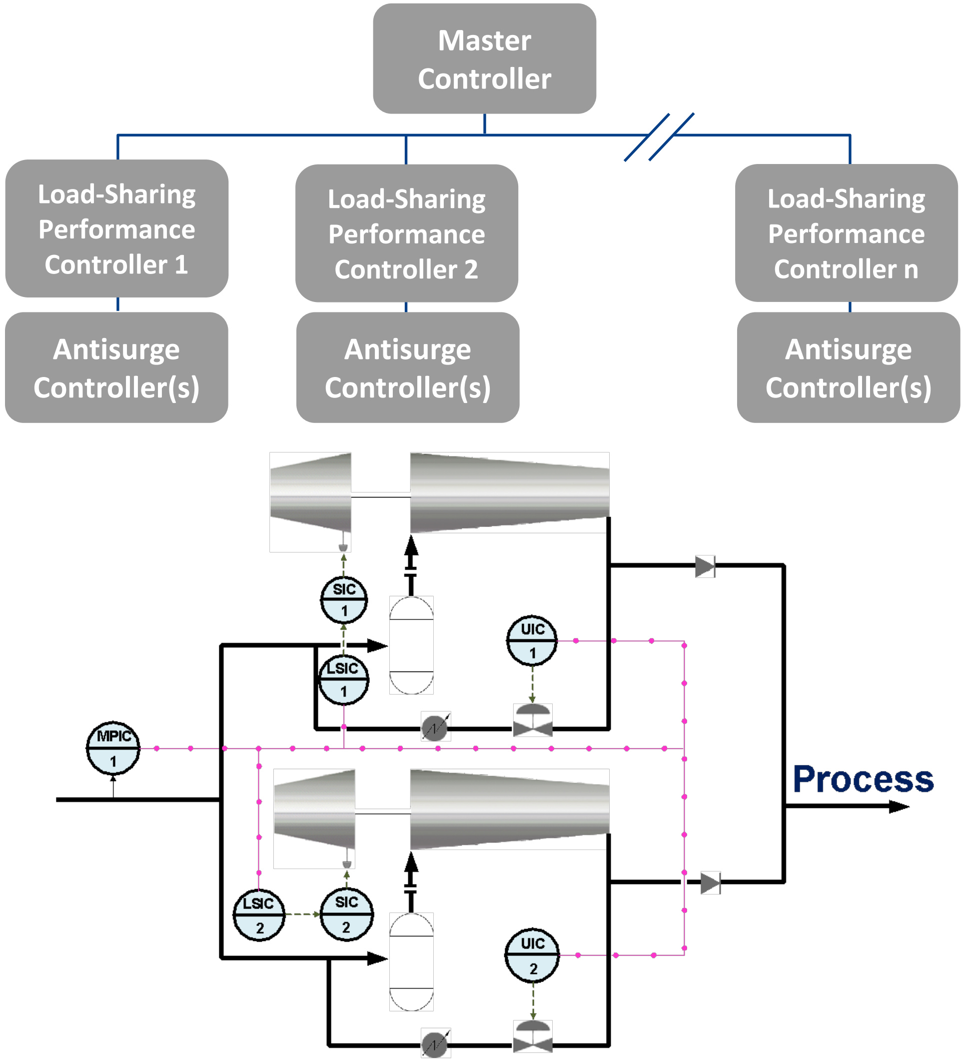
- Performance control loop may be too slow to react to a large disturbance
- Performance Override Control (POC) can be used to open the antisurge valve when a configured limit is exceeded
- When the operating point drops below the POC setpoint, normal a/s control is resumed
- Performance control will ultimately stabilize the operating point on its primary process setpoint





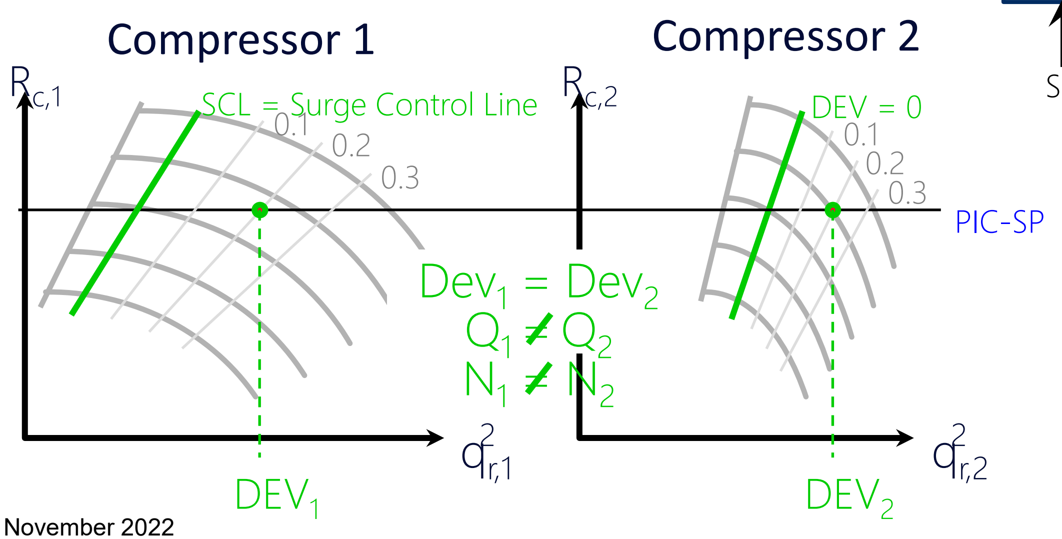
Parallel Load-Sharing Control

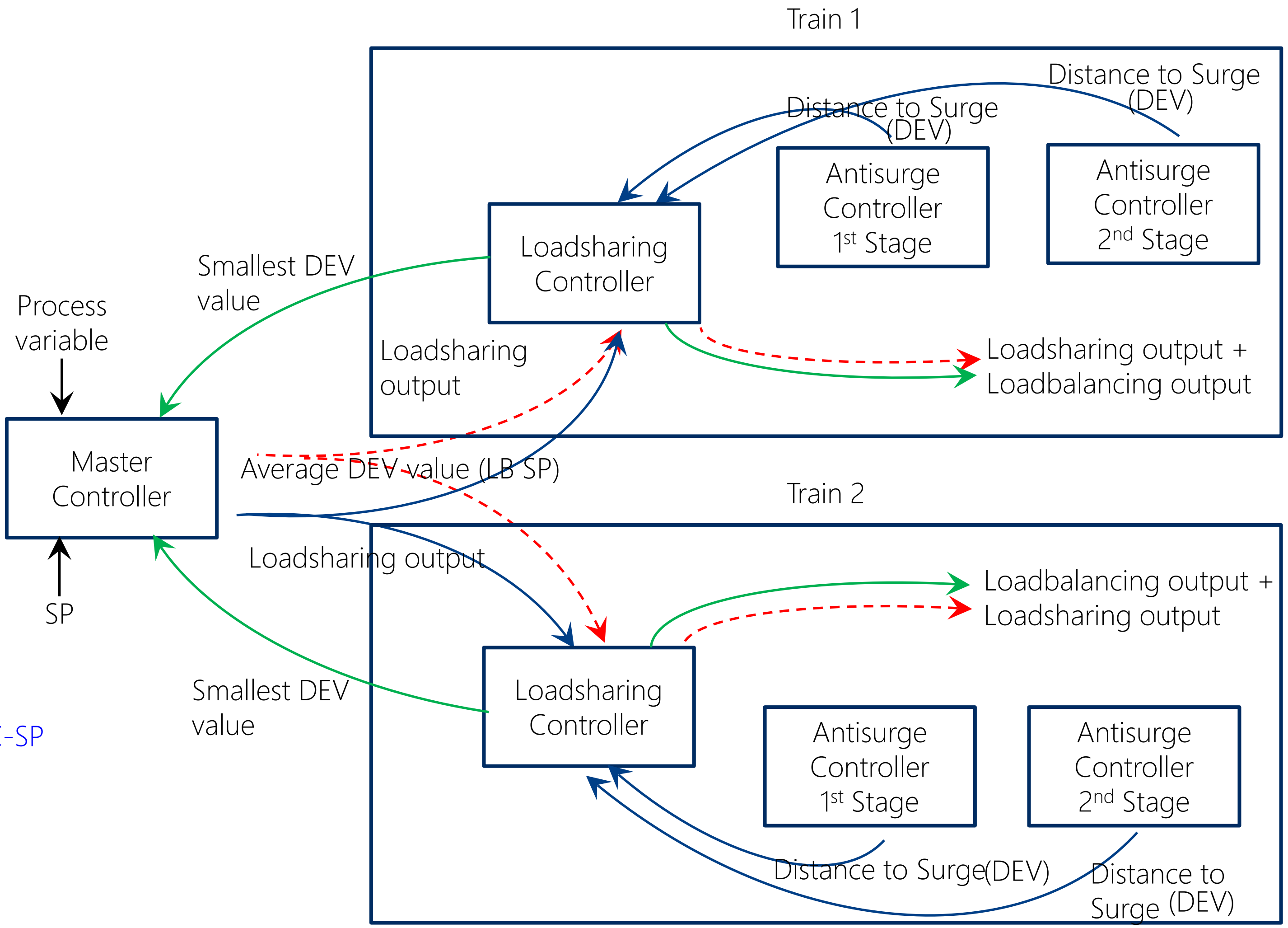
- Two-tier control response
- Primary load-sharing control response
  - Master controller regulates flow or pressure in a header through both load-sharing and antisurge control elements
- Secondary load-balancing control response
  - Keeps the parallel compressors from recycling until all are operating at their respective surge control lines



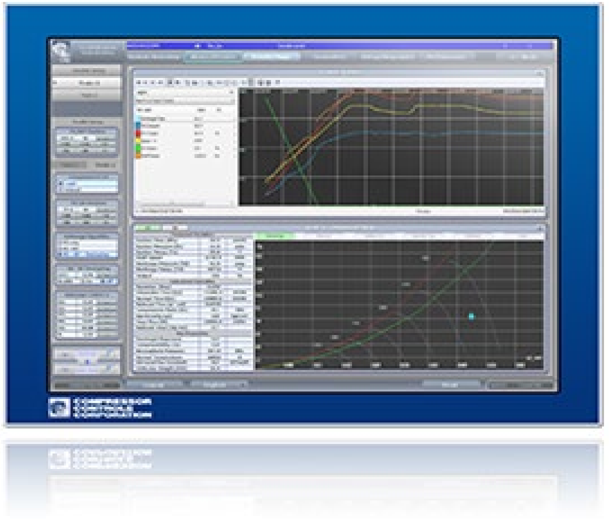
Equidistance Load-Balancing Control

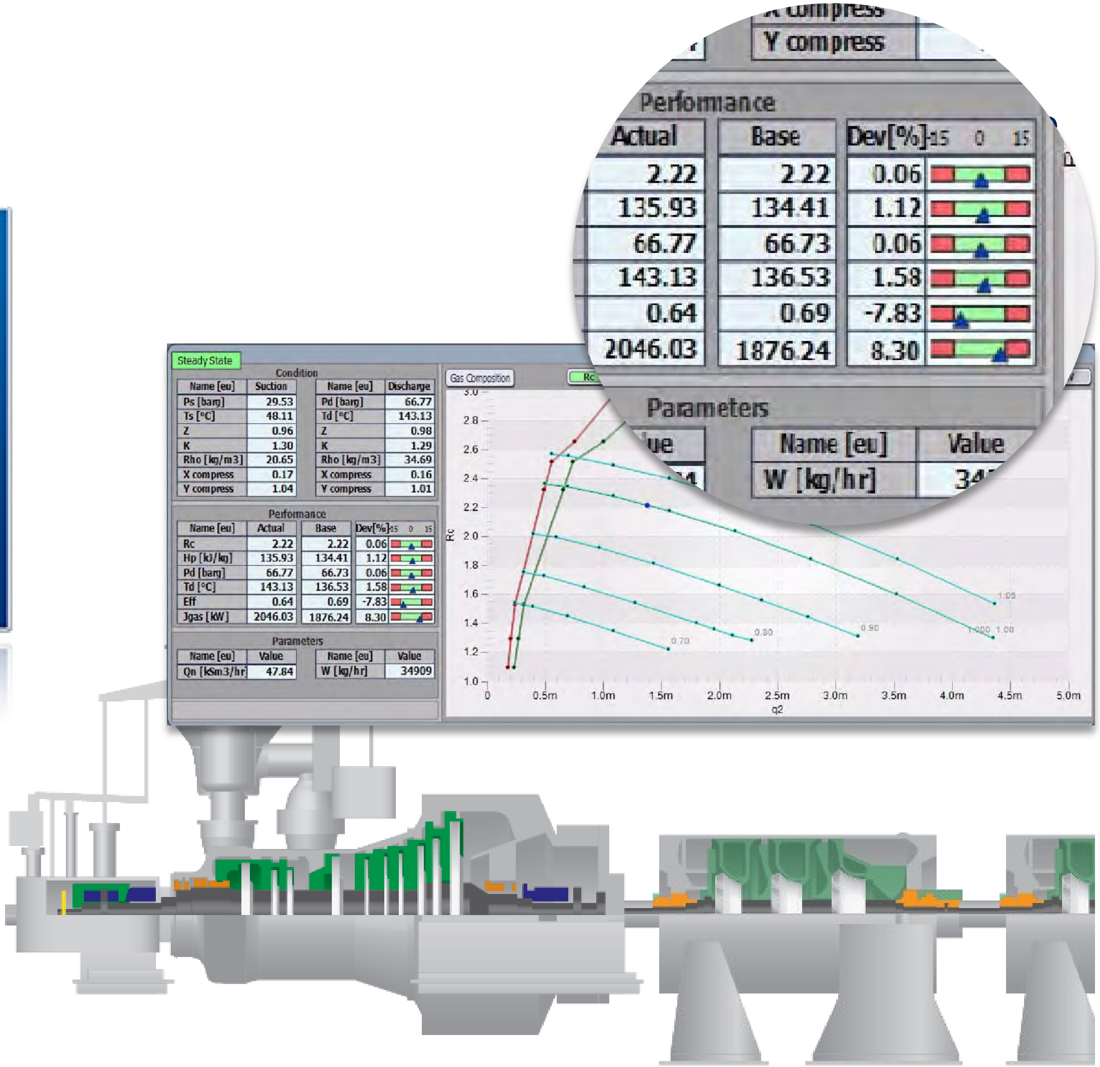
- Loadsharing controllers use the lowest calculated distance (DEV) between the SCL and operating point for the load balancing PV
- The SP is the averaged DEV value from all parallel Load sharing controllers
- The Load-Balancing response is added to the Master's primary response





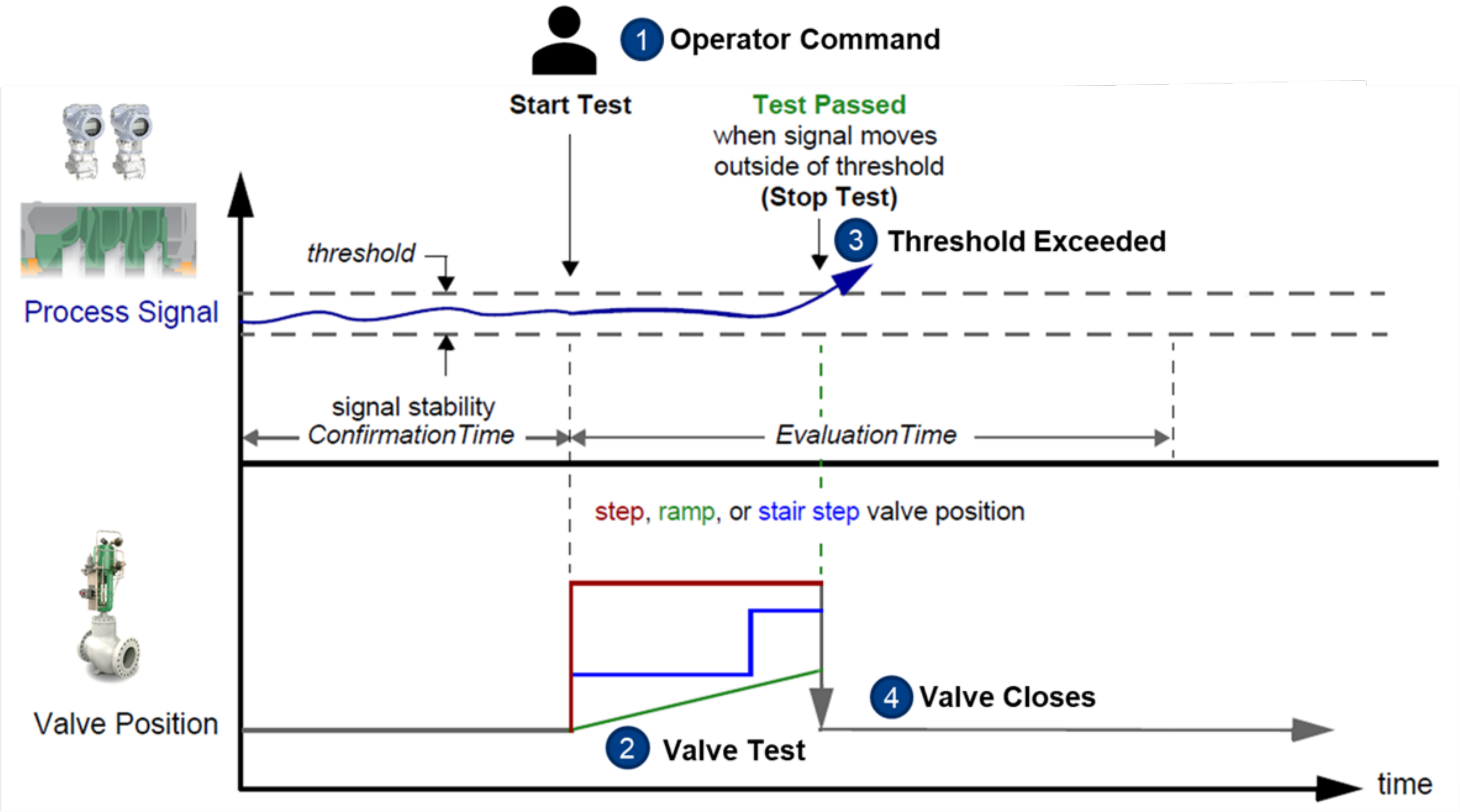
Monitoring the Turbomachinery & Compressor Performance Advisor (CPA)





- Quantifies degradation of compressor and inter-stage cooler, and detects fouling to prevent unplanned shutdown
- Local HMI provides monitoring as well high-speed event archiving (less than 150ms)

Valve Exerciser for Safely Detecting Valve Anomalies (Such as Stiction)



(WIPO Reference: WO2018195173A1)

Antisurge Controller

- Flow (dPo1)
- Proximity to Surge (Ss)
- Valve Position (pos)

Speed Controller

- Turbine Speed (N)
- Valve Position (pos)

Control application continuously checks for process stability.

Upon operator command, application will safely exercise valve while monitoring process.

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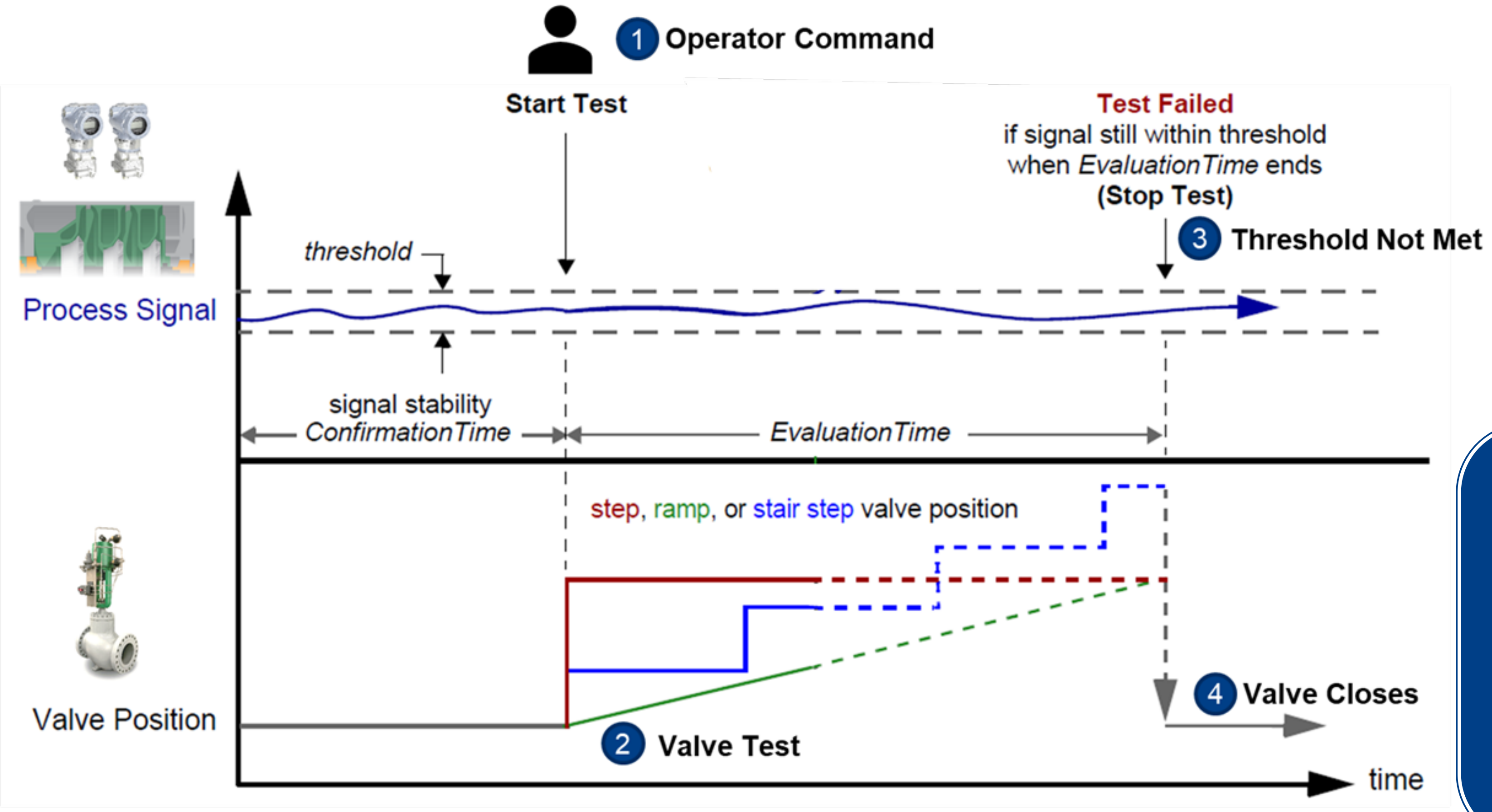

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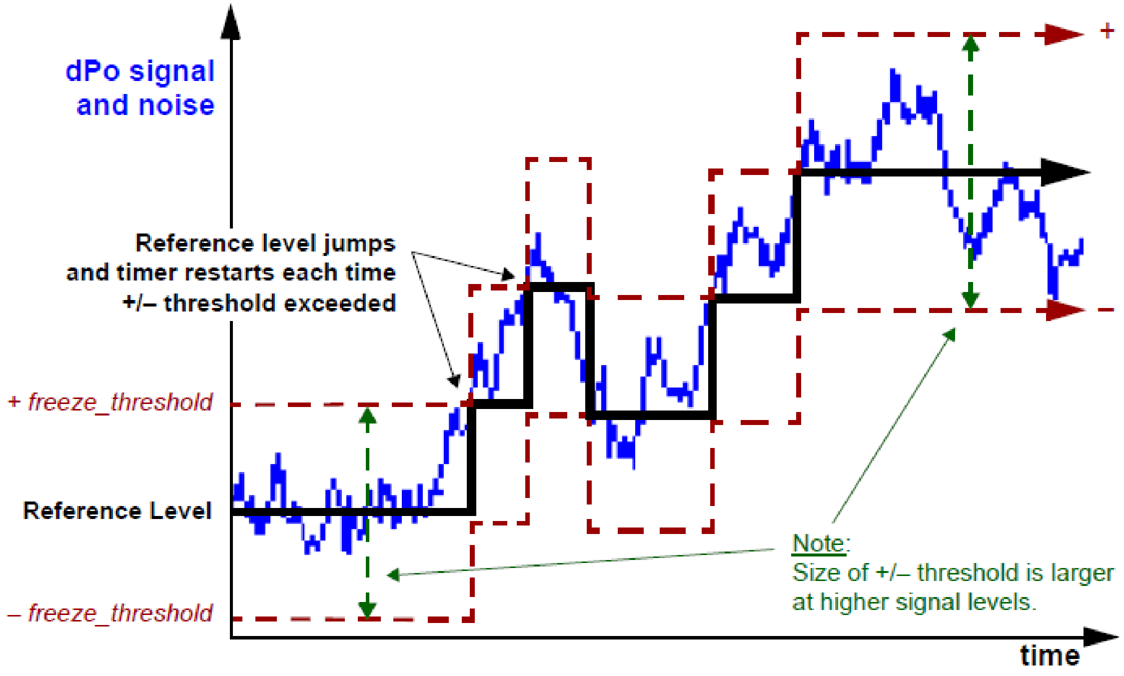
Transmitter Drift and Freeze Detection



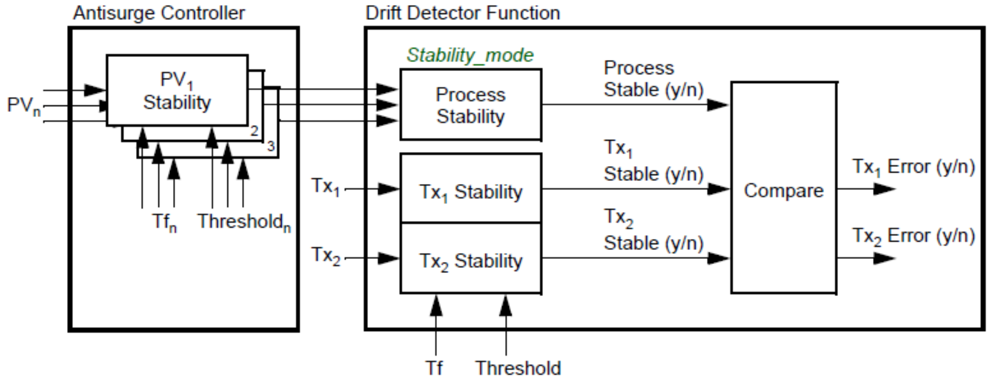
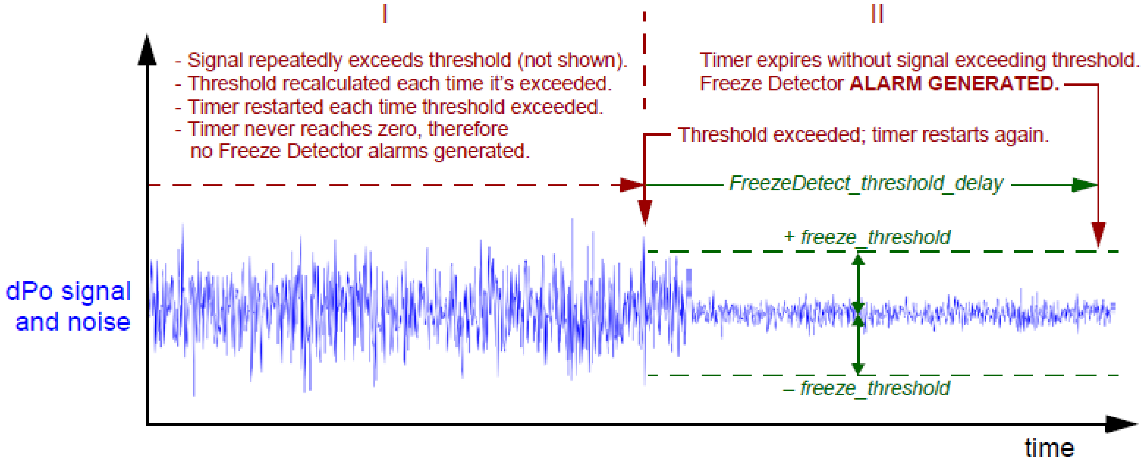


Figure 1-1 Drift Detector Function Overview



- Transmitter problems are a common cause for process upsets
- Fallback and Drift / Freeze algorithms minimize disturbances

Benefits of Integrated Turbomachinery Controls

Integrated turbomachinery controls, if designed and configured properly, offer the following benefits:

- Increased energy savings. Tighter antisurge control margins reduce recycle rates compared to traditional controls, especially during partial machine loading.
- Lower emissions via reduced suction pressure control margins and reduced CO_2 venting.
- More stable operations. Compressor recycle valves help prevent the CO_2 compressor suction pressure from dropping too low (in the event of a CO_2 stream disturbance), or the discharge pressure from becoming too high.
- Easier startup. Automatic coordination for the control actions on the antisurge valves loading the train.

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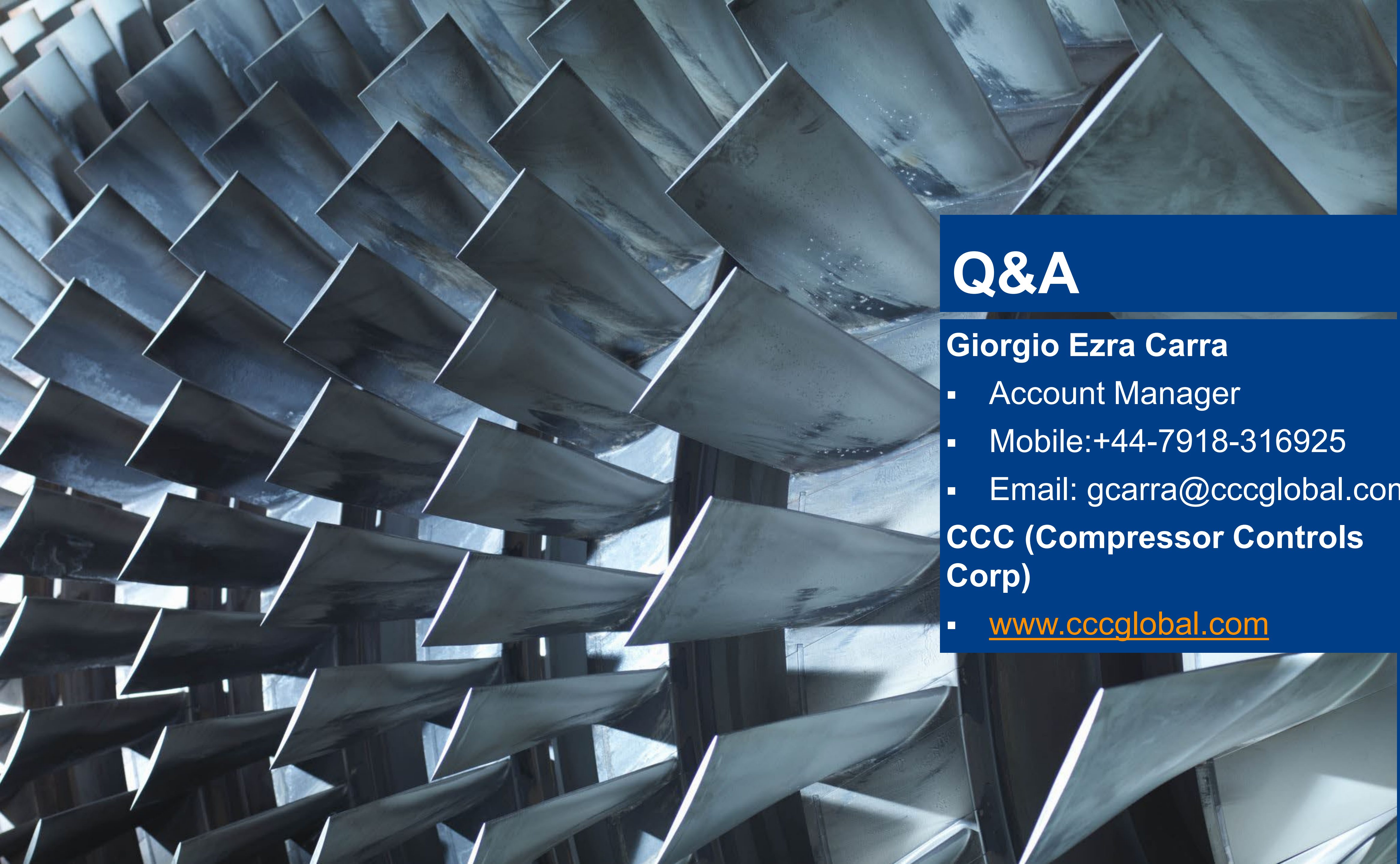

Q&A

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