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# **Case Study of Reverse Rotation Of Centrifugal Compressors - Impacts, Causes & Mitigations**

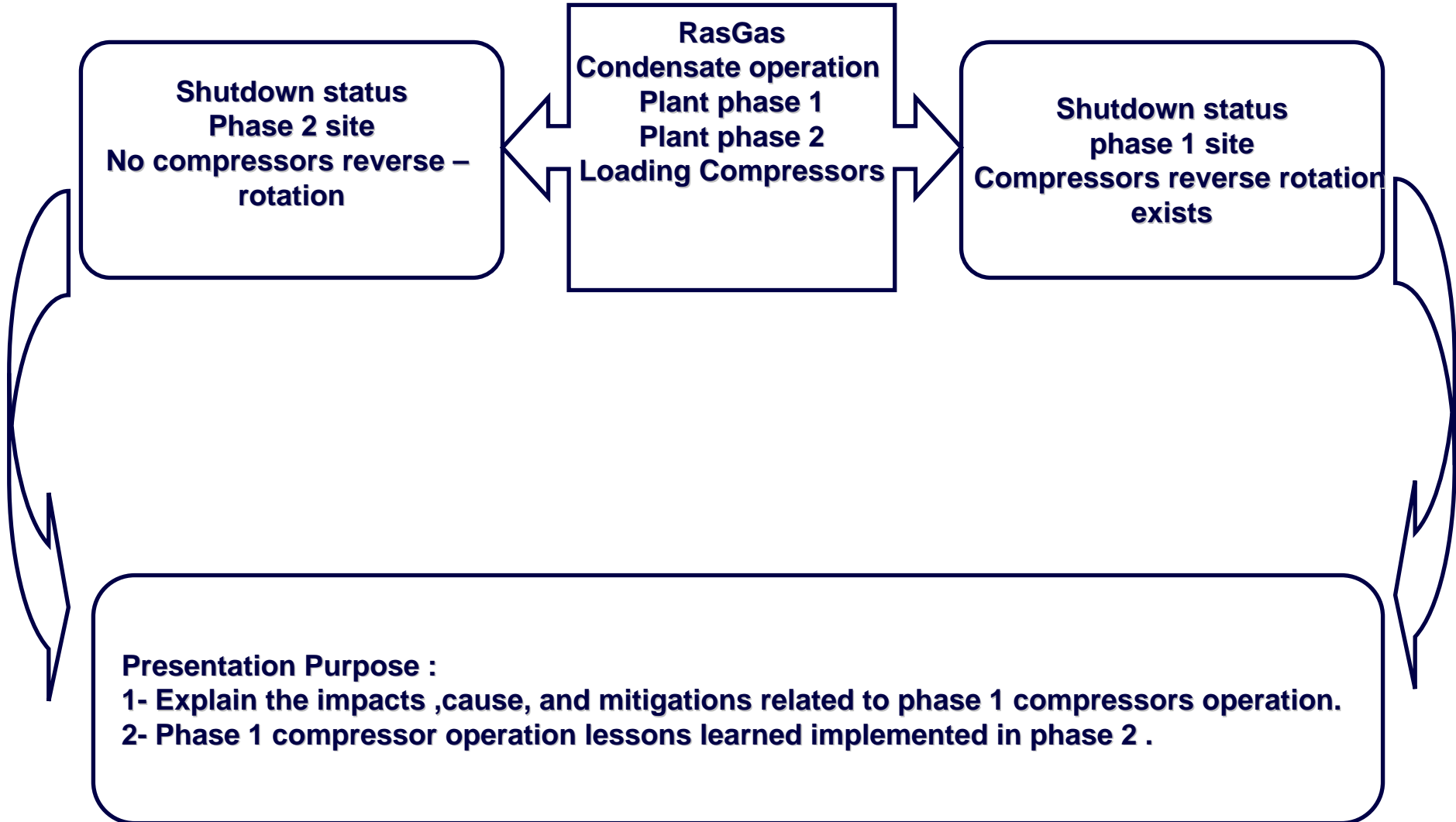
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Presented by Amr Gad**

# Outline

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- Introduction
- Process overview
- Compressor design & construction
- Narrative of reverse rotation events
- Cause of reverse rotation
- Possible impacts of reverse rotation
- Mitigating actions taken
- Lessons learned
- Conclusion

# Introduction



# Process Overview

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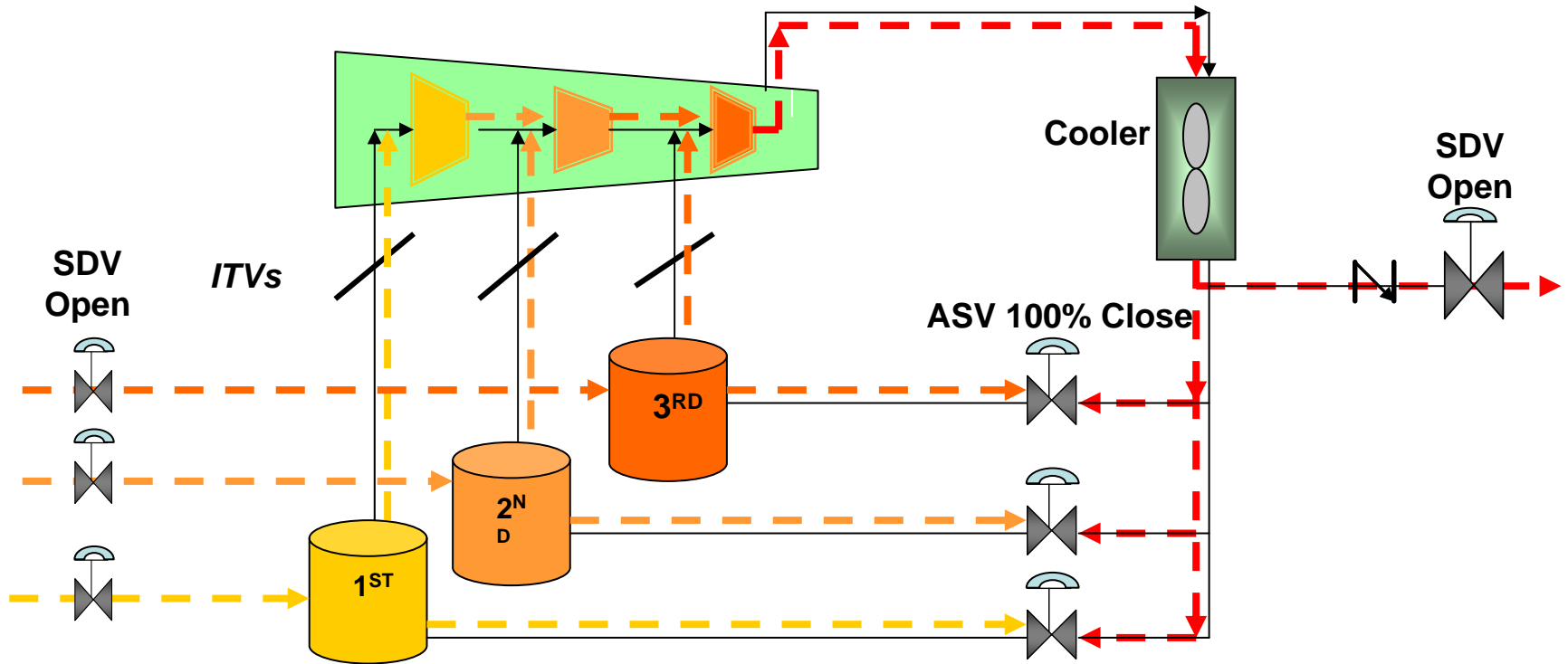
## Phase 1 (since 2005)

- Six compressors.
- Design pressure ratio for LP ,MP, HP is about 3 for each stage ( $P_d / P_s$ ).
- Design overall pressure ratio for the machine about 28 ( $P_d / P_s$ ).
- Volume of suction vessels LP, MP, HP more than 50 meter cube for each.

## Phase 2 (since 2009)

- Four compressors in operation.
- Similar design pressure ratio & overall pressure ratio as phase 1.
- Triple the volume of suction vessels compare to phase 1.

# Process Overview



Machines During Normal Operation

# Compressor Design & Construction

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## Phase 1

- Unit configuration: Fixed speed electric motor & gear box & compressor.
  - Compressor rated at: 3.7MW
  - Motor rated at: 4.2 MW
  - Gear box speed: 1480 / 10258 RPM
  - Compressor operating speed: 10258 RPM
- Seal configuration: Unidirectional dry gas seal.
- Bearing construction:
  - Compressor: Tilt pad self equalizing
  - Motor: Cylindrical sleeve bearing
- Gear box design: Double helical.
- Lube oil: Rundown tank with two AC pumps (Main & Auxiliary).

# Reverse Rotation Events

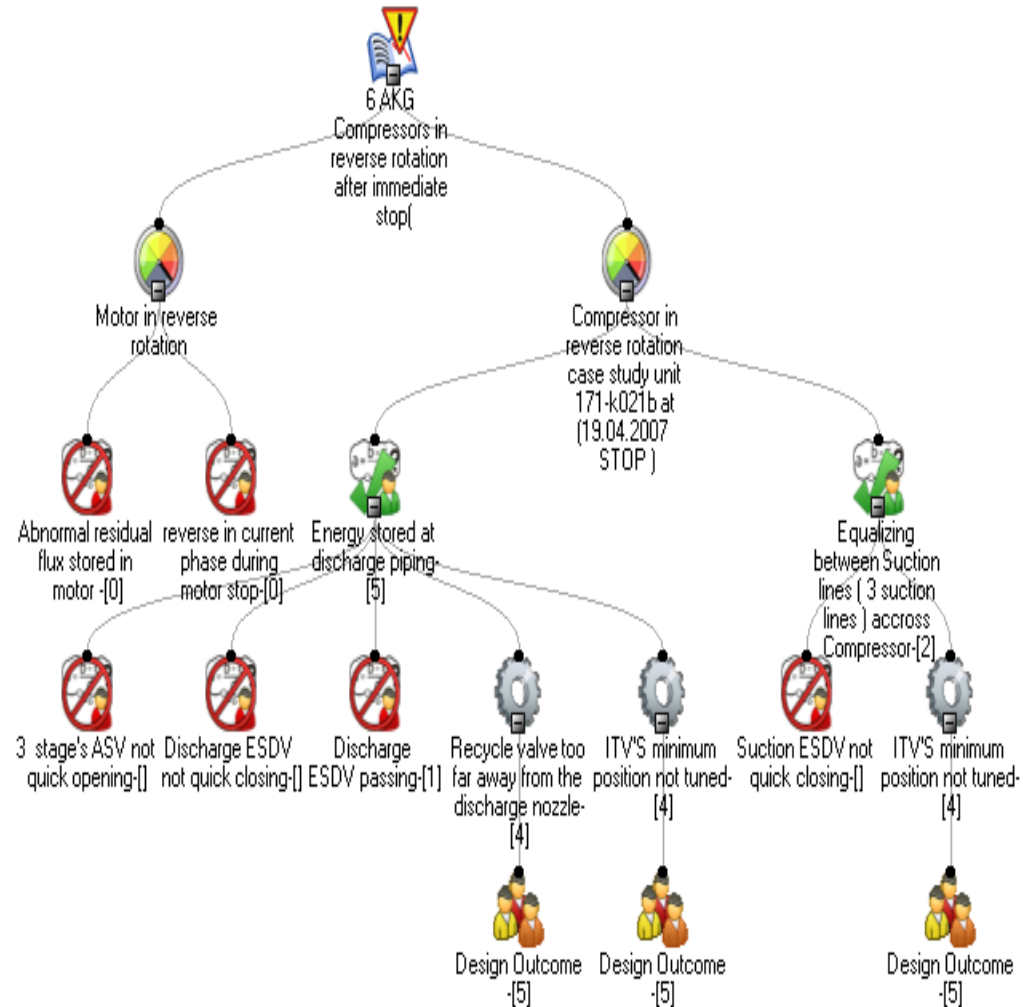
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- Reverse rotation happened since commissioning of the machines.
- However, they were only discovered after 18 month of units operations. Late discovery was due to:
  - No reverse rotation detection system installed.
  - No prior experience in-house with reverse rotation in this type of process configuration.

# Cause of Reverse Rotation

## RCFA findings:

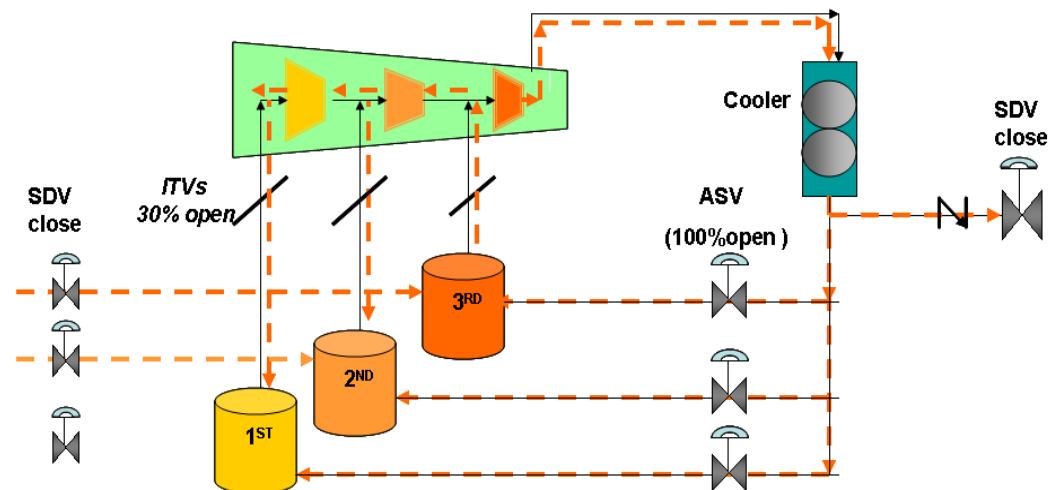
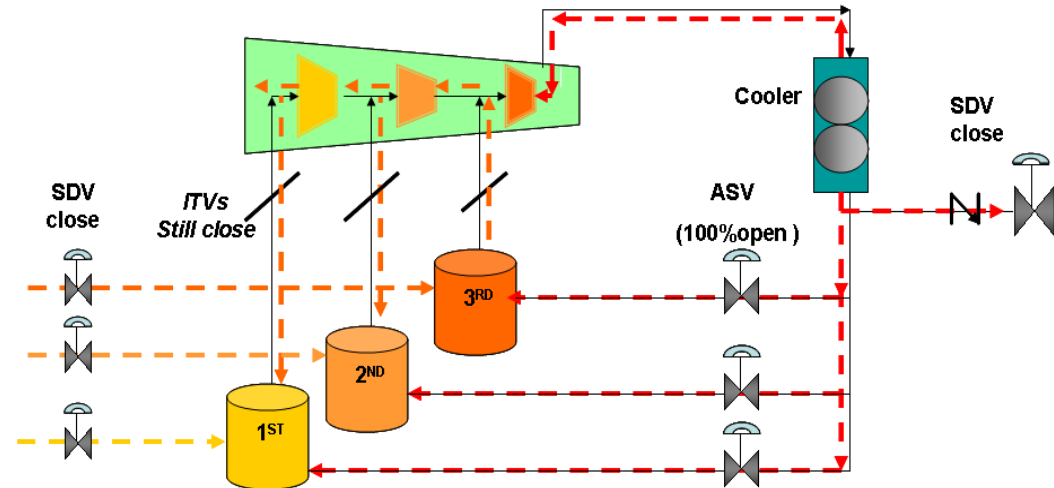
- Reverse hydraulic flow due to large amount of entrapped hydrocarbon volume in the piping and suction vessels of the MP & HP sections.





# Cause of Reverse Rotation

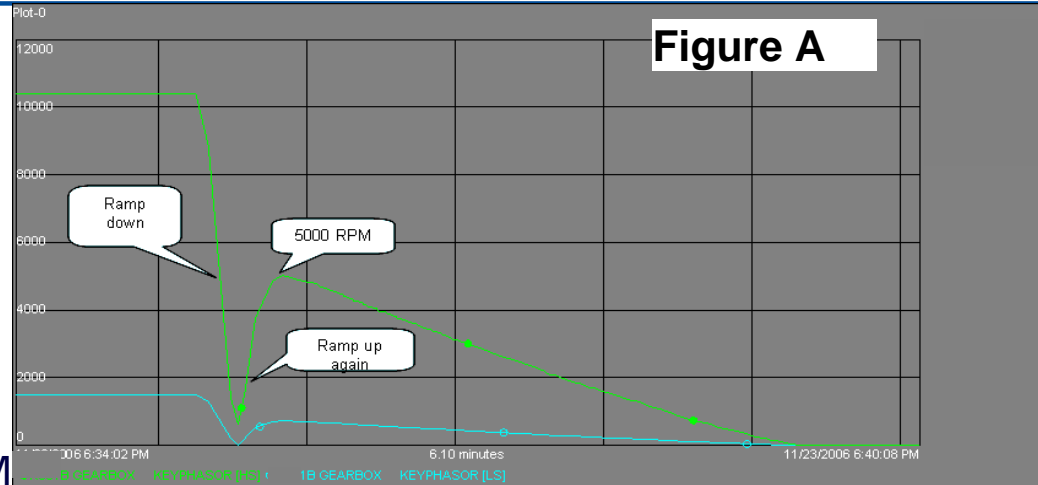
- Hydraulic flow occurs after 10-15 seconds from a stop command till compressor coast down to zero RPM speed.
- Hydraulic flow during the reverse rotation from zero speed till 5000 RPM and back to zero again within 4 to 6 minutes.



# Cause of reverse rotation

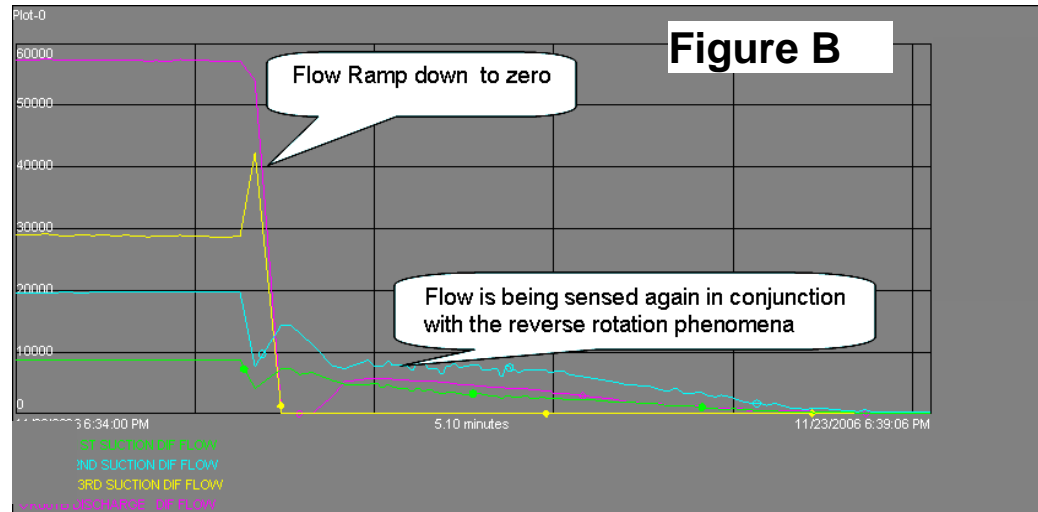
## Speed trend (Figure A)

- Unit stop very fast after stop command.
- Unit speed ramp up again in reverse rotation to almost 5000 RPM for the compressor.
- After speed reaches 5000 RPM it cost down again to zero speed in about 4-6 minutes.
- This phenomena is repeated each time the machine stops.



## Flow rate trend (Figure B)

- Showing flow exchange & equalizing between stages.



# Possible Impacts of Reverse Rotation

**Uncontrolled gas release from the compressors.**

**Existing unidirectional dry gas seal are not guaranteed for such modes of operations as per OEM guide lines.**

**Bearings damage**

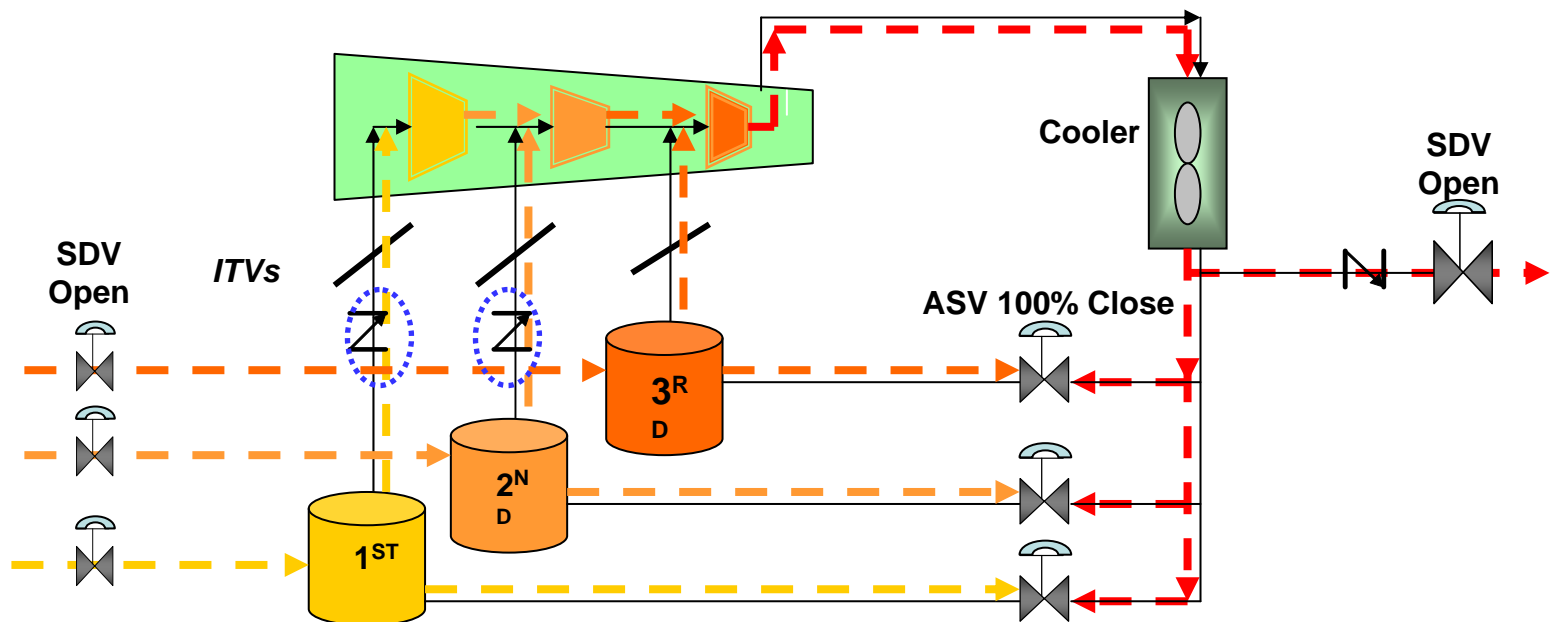
**Lube oil system design doesn't support reverse rotation with total electric power black out , as auxiliary and emergency pumps is AC driven and the overhead tank is designed for only 3 minutes .**

**Compressor components failure due to reverse rotation**

**No detailed study conducted by OEM to confirm impacts on various machines components ( Impeller vanes, diffusers, Labyrinth seals ,...etc ).**

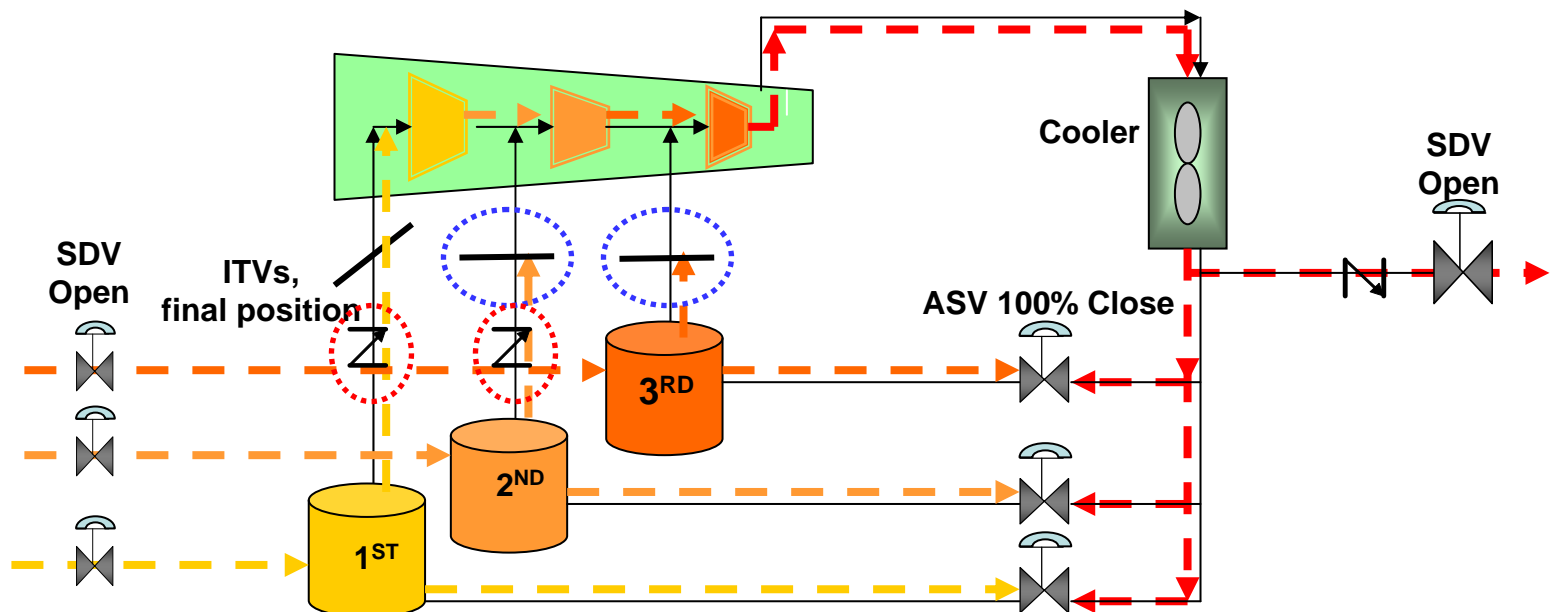
# Mitigating Actions. Phase 1 Compressors

- Minimize the number of units starts and stops until modify the system.
- Special project to install check valves installation at the suction of the LP & MP for the units.



# Mitigating Actions. Phase 2 Compressors

- Interim - modified the I&C for the ITV's of the MP & HP to fully close during machine stop.
- Final - install check valves at the suction of the LP, MP and immediately after the discharge.



# Lessons Learned

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- Dynamic stimulation requirements for such process configurations.
- Mitigating actions to eliminate reverse rotation should consider:
  - ITV modification for complete closure during shutdown.
  - Installation of check valves at suction lines.
- Machines construction should include mitigating design:
  - Bidirectional seal will eliminate risk from reverse rotation
  - Center pivot for tilting bad can accommodate reverse rotation better than offset pivot design
  - API standard is for 3 minutes run down tank design and so, emergency DC pump is an advantage

# Conclusions

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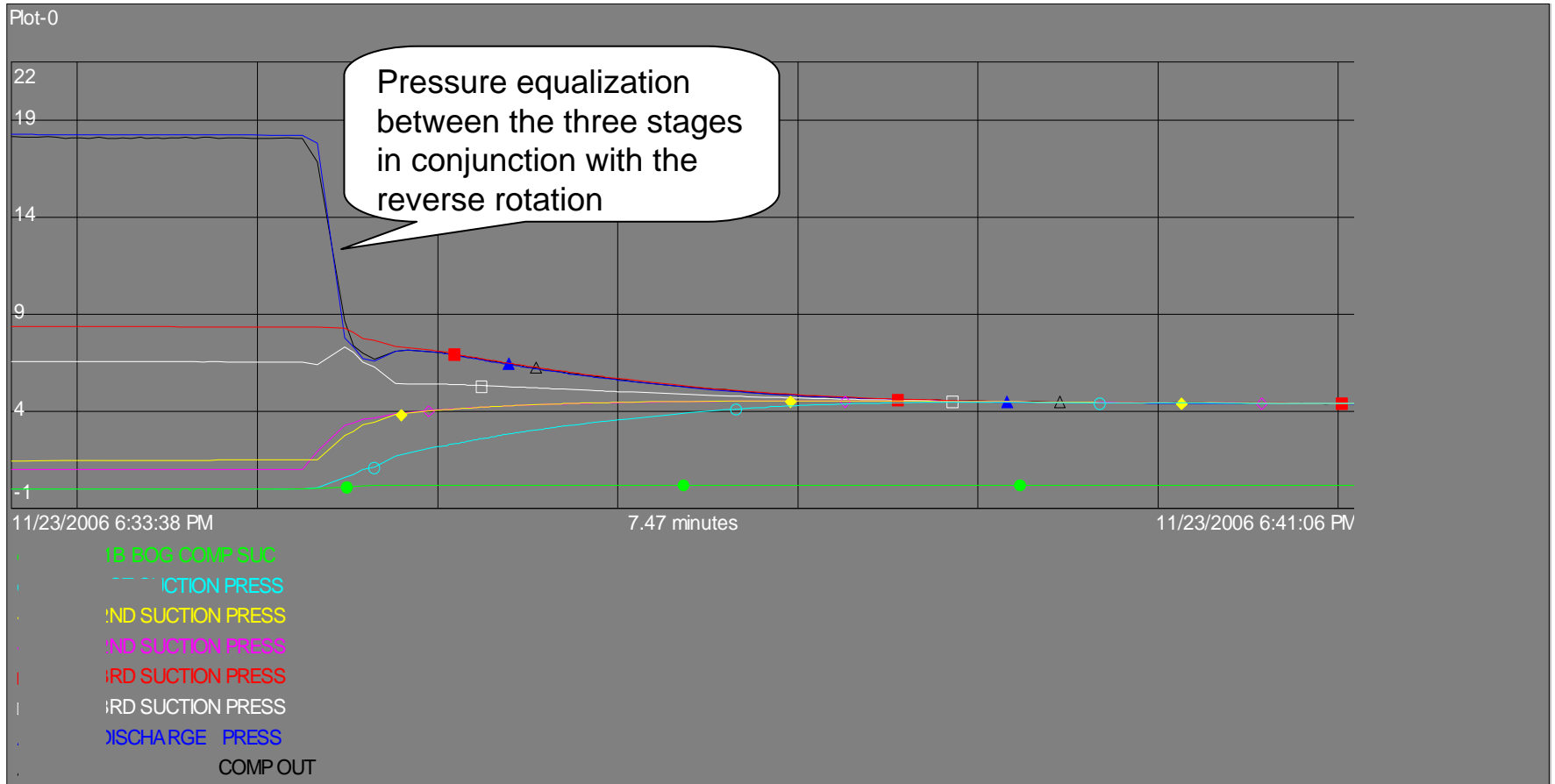
- Reverse rotation phenomena have potential to occur in the LPG refrigeration cycles.
- Reverse rotation phenomena is more common in the motor driven compressors with relatively low machine inertia.
- Detailed surveillance of coast down speed trends of new units is recommended to ensure detection of Reverse Rotation:
  - Reverse rotation phenomena may not increase vibration or axial movements above alarm values

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**Thank You**



# Pressure trends for unit stop



- ASV improper function is potential cause for reverse rotation during coast down.
  - Experienced in LNG BOG compressor when opening time upon shutdown is more than 2 seconds due to valves stuck or instruments failures.

