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TURBOMACHINERY LABORATORY
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Dynamic Analysis of a Multi-Stage Compressor Train

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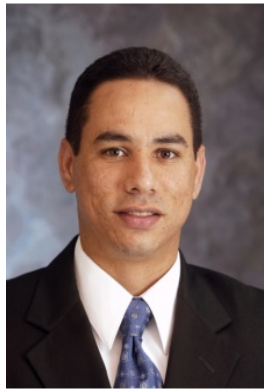
Slide 2: Presenter/Author Bios



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- 14 years experience modeling pipelines and associated machinery
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- Program Director, Southwest Research Institute
- Highly experienced in Rotating machinery, energy generation, power cycles, and fluids
- Ph.D., Mechanical and Aerospace Engineering, University of Virginia, 1996
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Short Abstract

A complex multiple-stage compressor train which is part of an off-shore booster installation was facing process and mechanical related problems. The frequency of these problems has increased lately leading to frequent trips and shut downs. These interruptions affect the operation of the plant and resulted in a loss in production and a subsequent loss of revenue to the company.

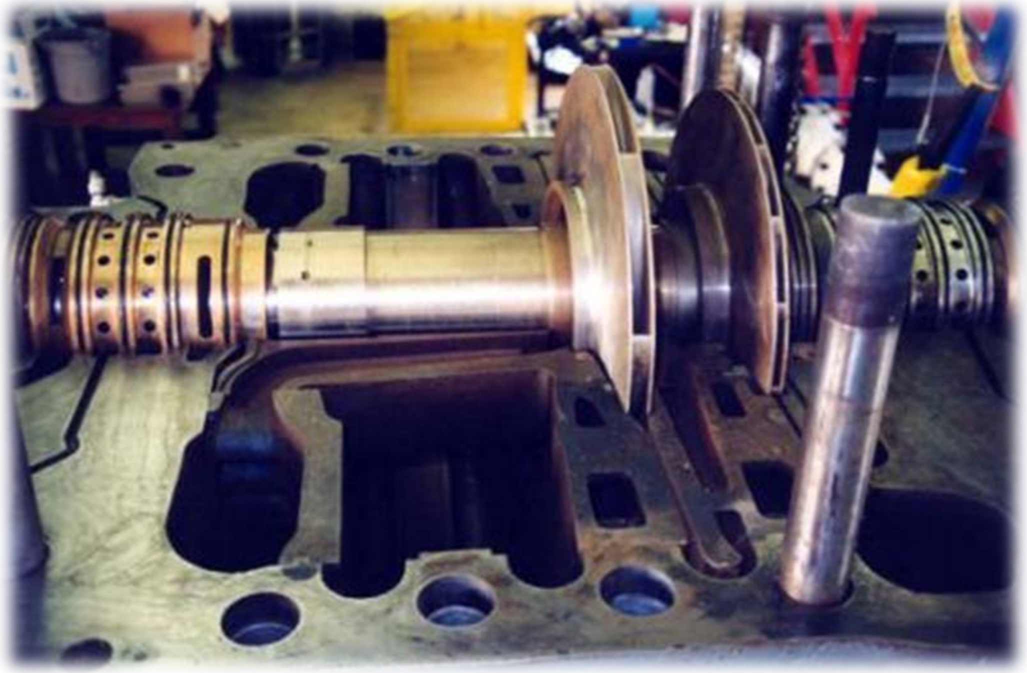
The platform contains two similar compressor trains consisting of a four-stage compressor with a gas turbine driver. Each train is fitted with an integrated turbine compressor control panel. Thus, a detailed dynamic system simulation of the subject compressor trains was performed in order to provide a series of recommendations that would improve the safe operation and increase the reliability of the compression systems. Thus, results of the analysis and some of the recommendations obtained are presented in this case study.

Presentation Overview

- Background and Introduction
- Case Study
- Computational Model
- Dynamic Simulation Analysis
- Summary and Conclusions

Background

- Process and mechanical related problems on the multiple-stage compressor trains
- Machine frequent trips and shut downs
- Several surge events in the past two years and a catastrophic machine failure
- Loss in production and consequences of lost revenue for the company



Introduction

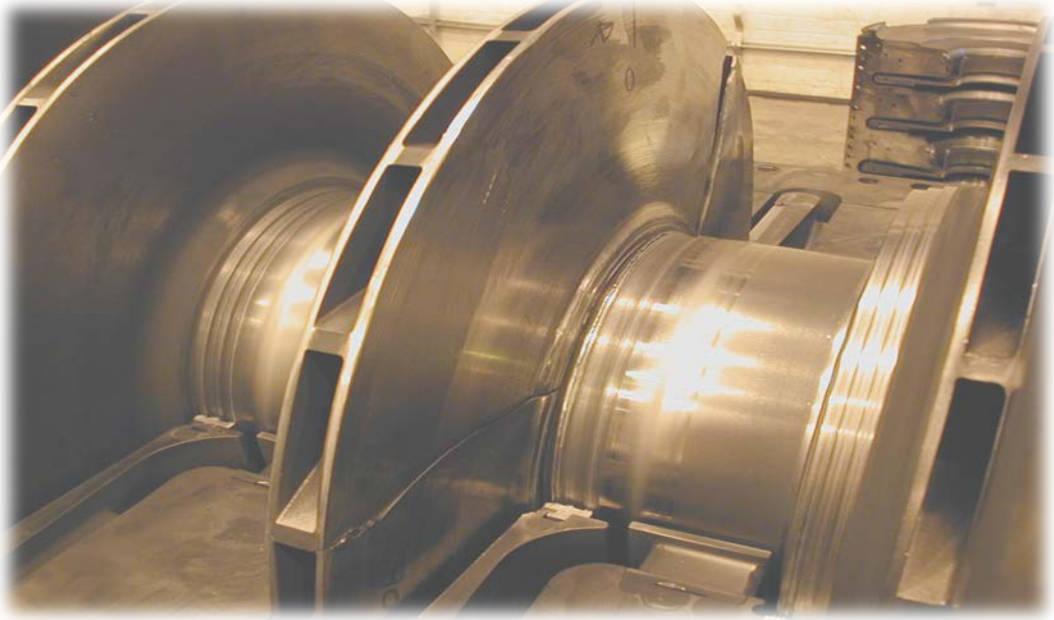
- A four-stage centrifugal compressor is driven by a gas turbine
- Each stage has its own dedicated anti-surge loop and cooling system
- The trains are fed with gas from different production fields
- Compressor trains are used to boost the pressure of natural gas coming from off-shore production fields to an on-land processing facility

Case Study

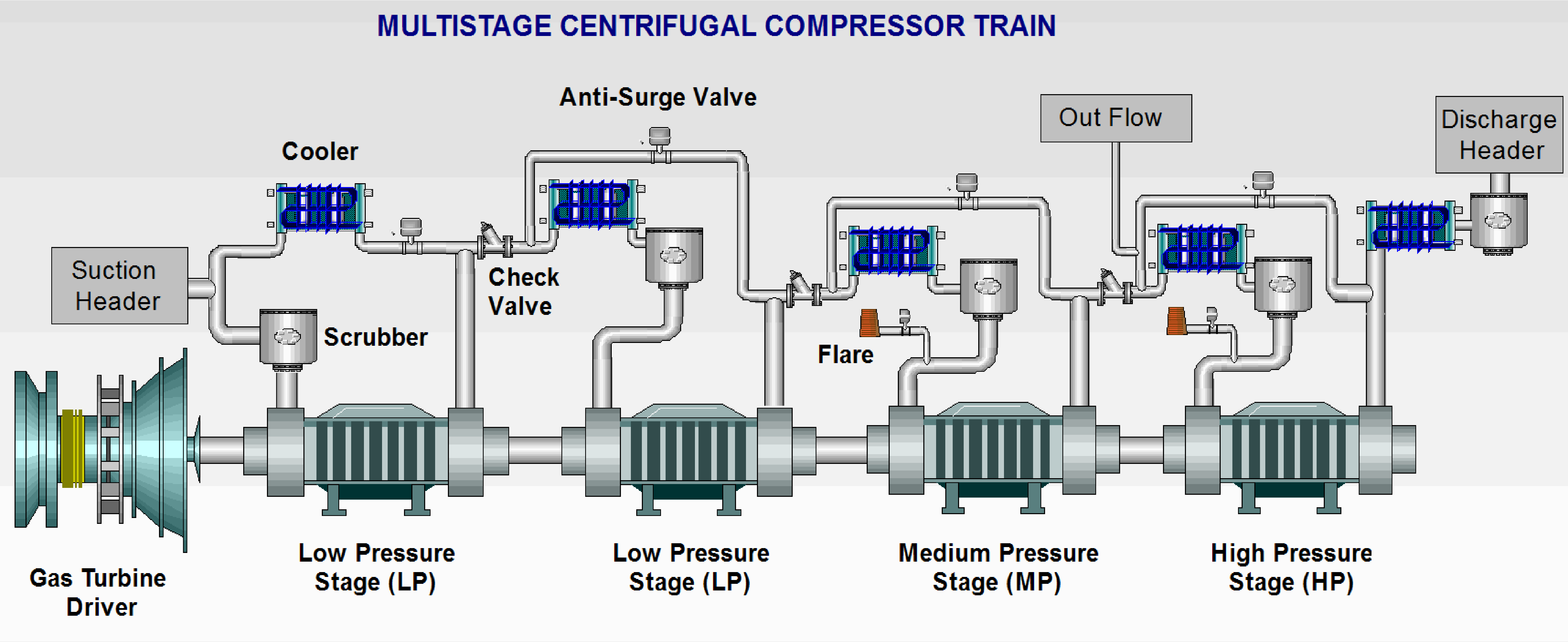
- Analyze an existing compressor train
  - A site visit was performed to review and understand the existing anti-sure control system
- Build an accurate model of the compression train anti-surge system
- Evaluate different scenarios to provide recommendations to improve the system operation and reliability
- Parametric studies of Anti-Surge Valves (ASVs), Non-Return Valves (NRVs), Emergency ShutDowns (ESDs)

Compression System

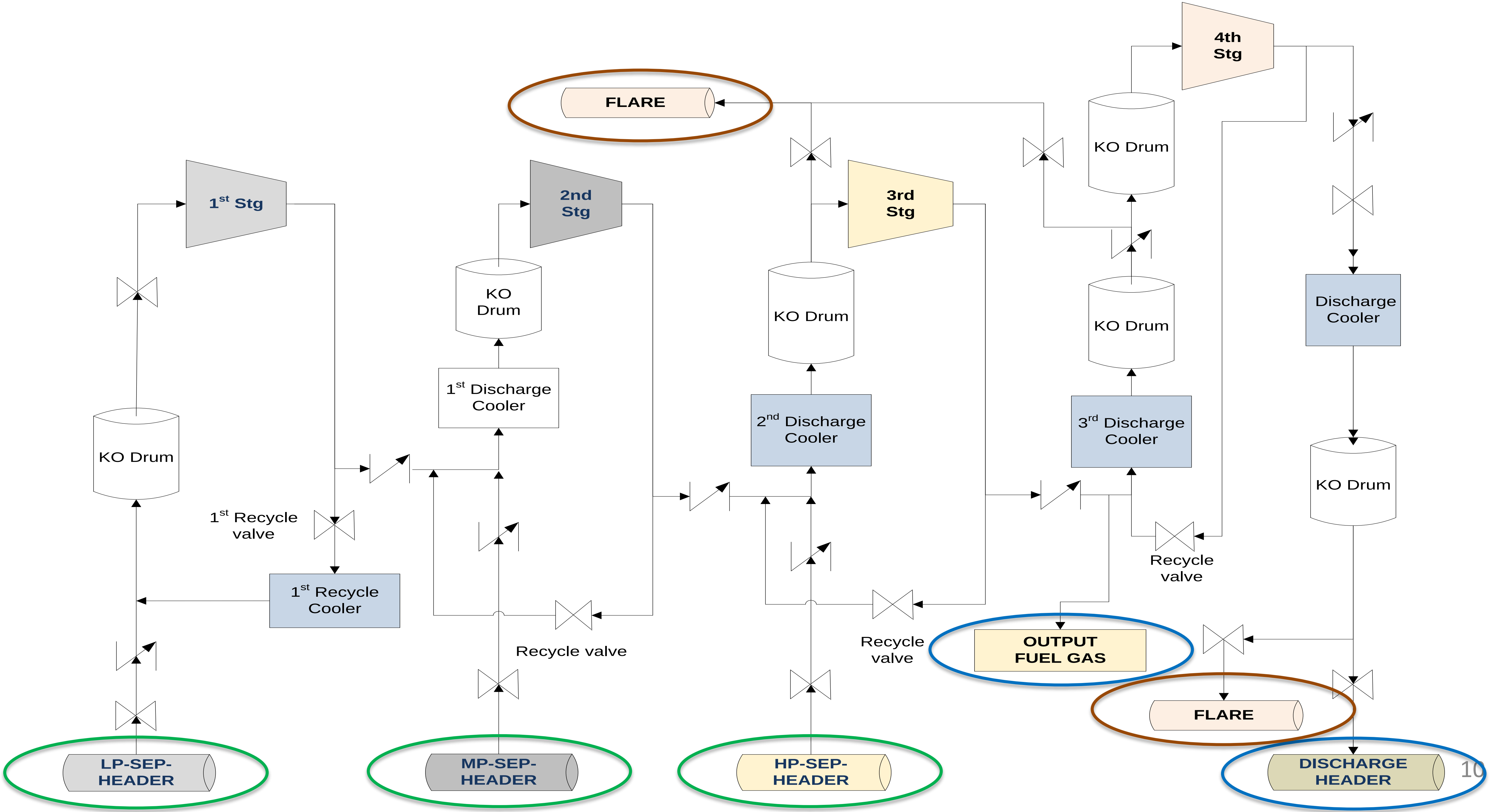
- Two booster platforms
- Two four-stage centrifugal compressors on each platform
- The compressor trains have low pressure (LP1 & LP2), medium pressure (MP) and high pressure (HP) stages
- Each stage includes a suction scrubber, cooler, recycle loop, and blowdown line
- Each train is fitted with an integrated turbine compressor control panel



Compressor Train General Schematic



Detailed Hydraulic Model Schematic



Model Characteristics

- Detailed programming of the ESD sequences and coastdown of the train
- Detailed piping volume arrays and anti-surge valve flow coefficient
- Flow and pressure boundary conditions
- Different influx gas compositions
- Gas turbine design power is corrected by elevation, ambient temperature, and running speed

Modeling Parameters

- Decay of Compressor Speed, N:

$$N(t) = \frac{J \cdot N_0^3}{J \cdot N_0^2 + P_0 \cdot t}$$

- Surge margin, SM:

$$SM = \left.\frac{Q_a - Q_s}{Q_a}\right|_{N=const}$$

- Operating Point, OP:

$$OP = \left.\frac{Q_a}{Q_s}\right|_{N=const}$$

- Turndown, TD:

$$TD = \left.\frac{Q_a - Q_s}{Q_s}\right|_{H=const}$$

Where:

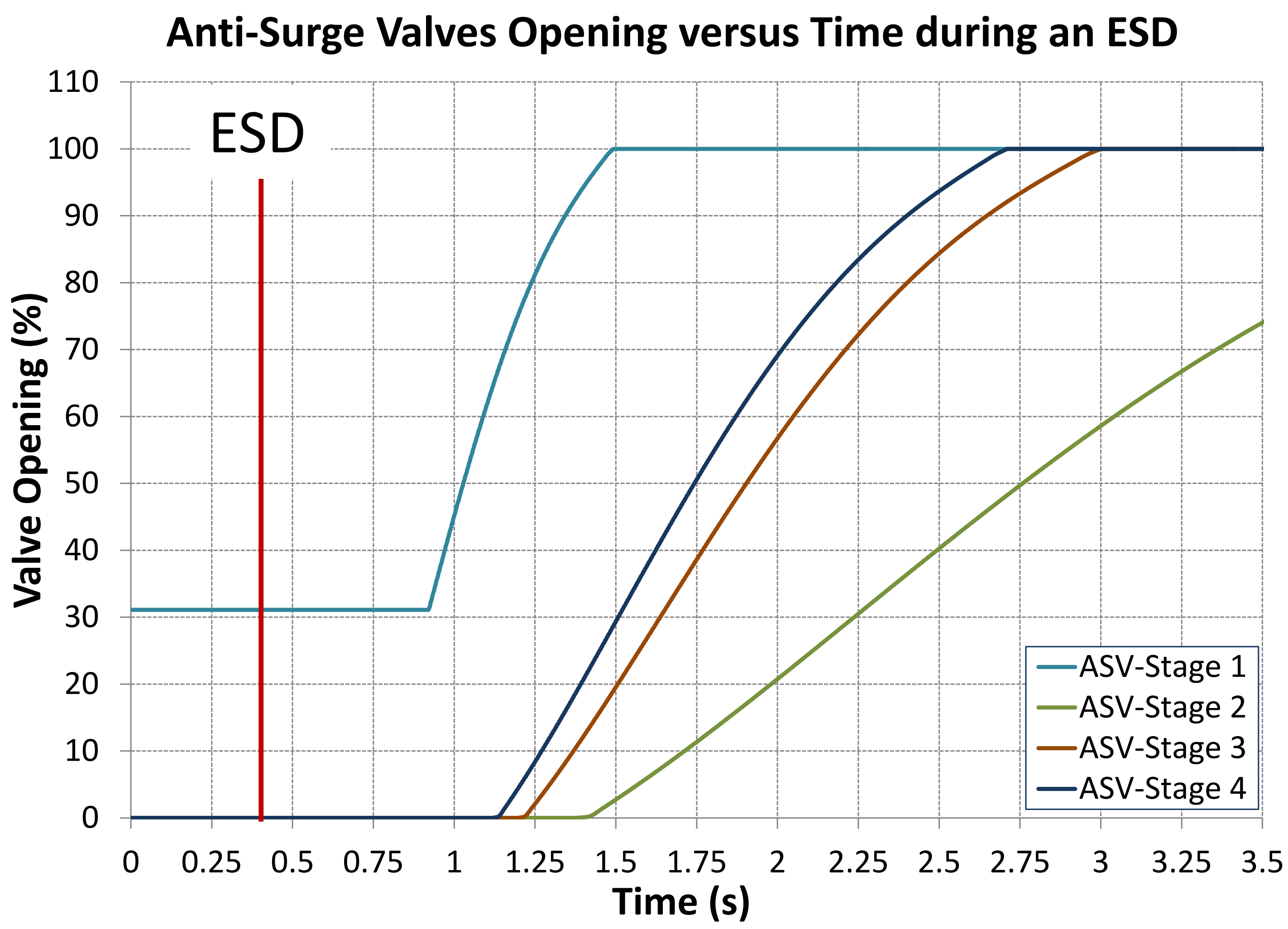
N	Compressor speed
N_0	Initial speed
J	Polar moment of inertia
P_0	Initial Power
Q_a	Actual Flow
Q_s	Surge Flow
H	Head

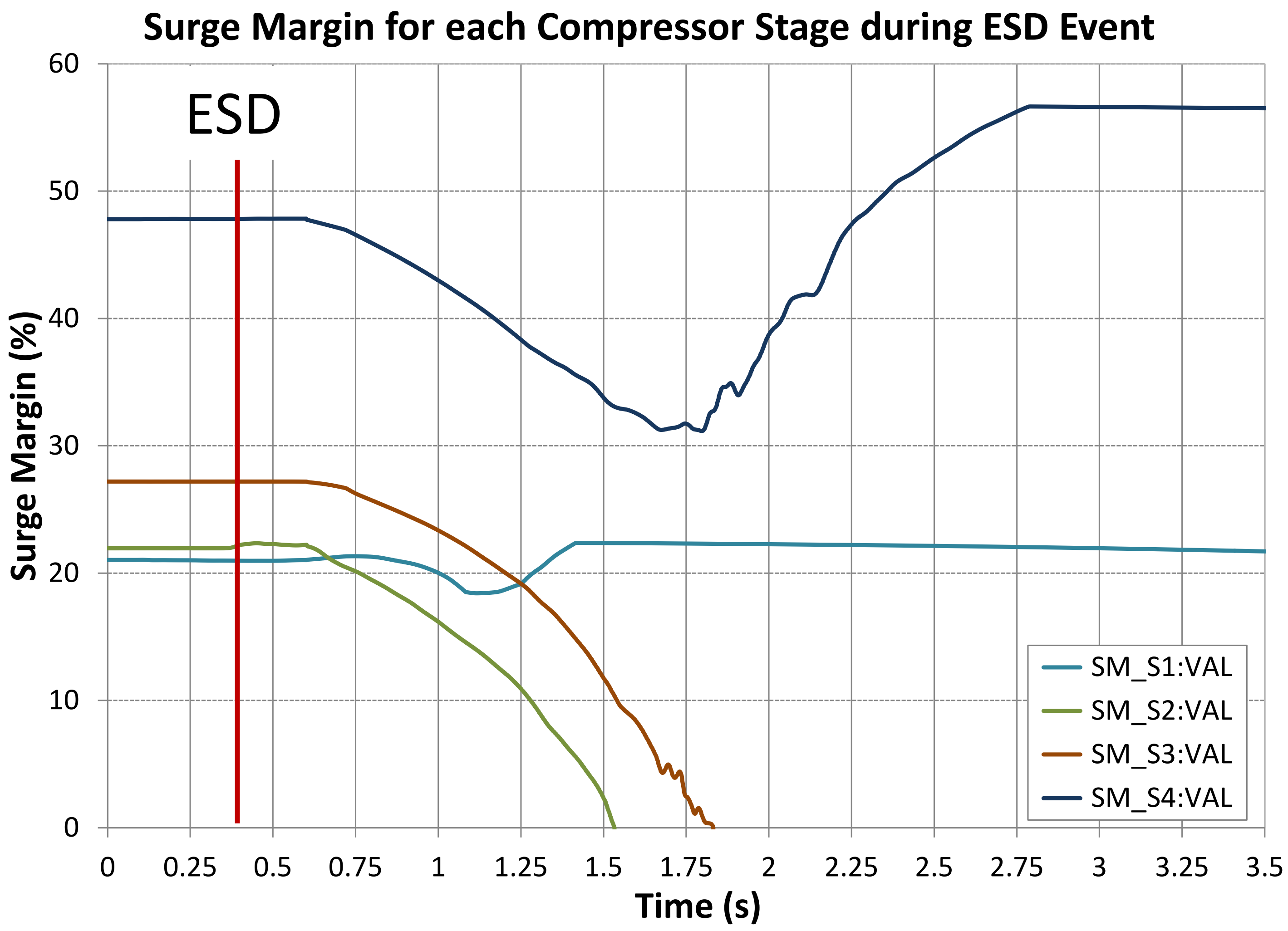
Evaluated Cases

- ESD Events – Existing Sequence
  - Modified sequences
  - Coast down Delay
  - Hot bypass
- Effect of Faster Opening of the Blowdown Valves
- Effect of Failure to Close of the NRVs
- Effect of NRVs in Series and Parallel
- System Control – Process Upset Conditions
- Molecular Weight Sensitivity Analysis

Dynamic Simulation Analysis

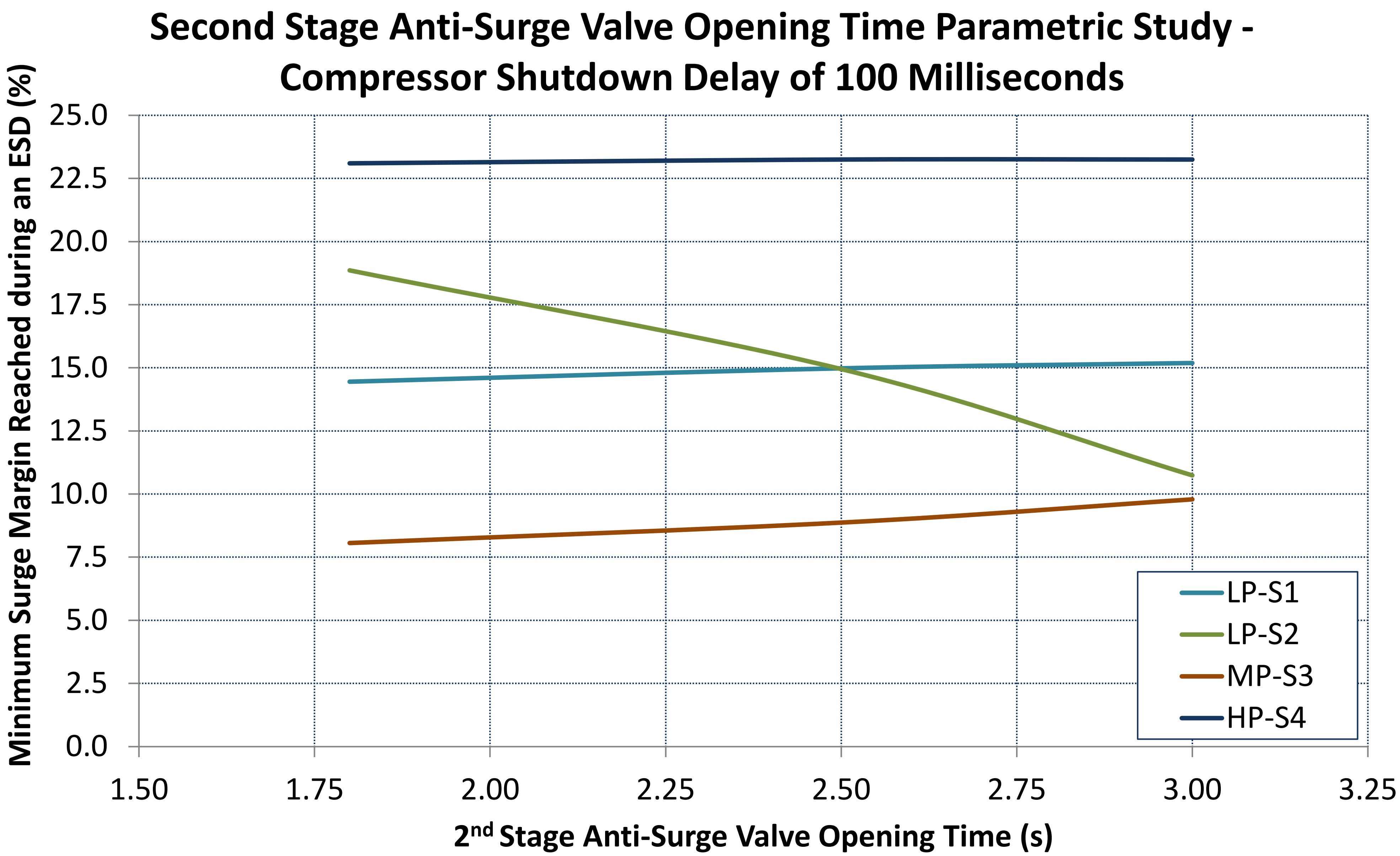
- Existing system and ESD event from normal operating conditions
- 2nd and 3rd stages surged at 1.0-1.25s after the ESD was started





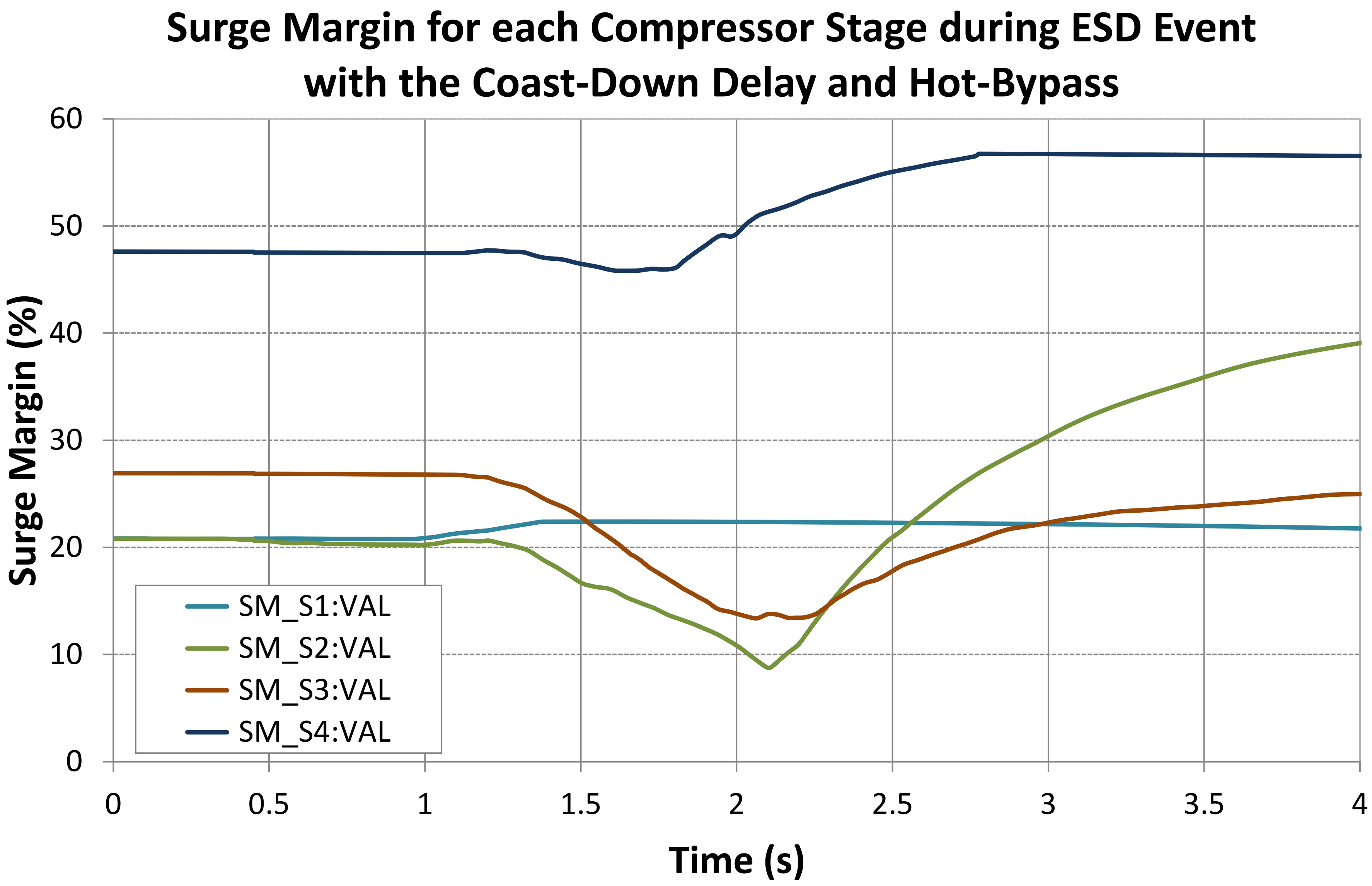
Parametric Study

- Opening and delay times of the anti-surge valves



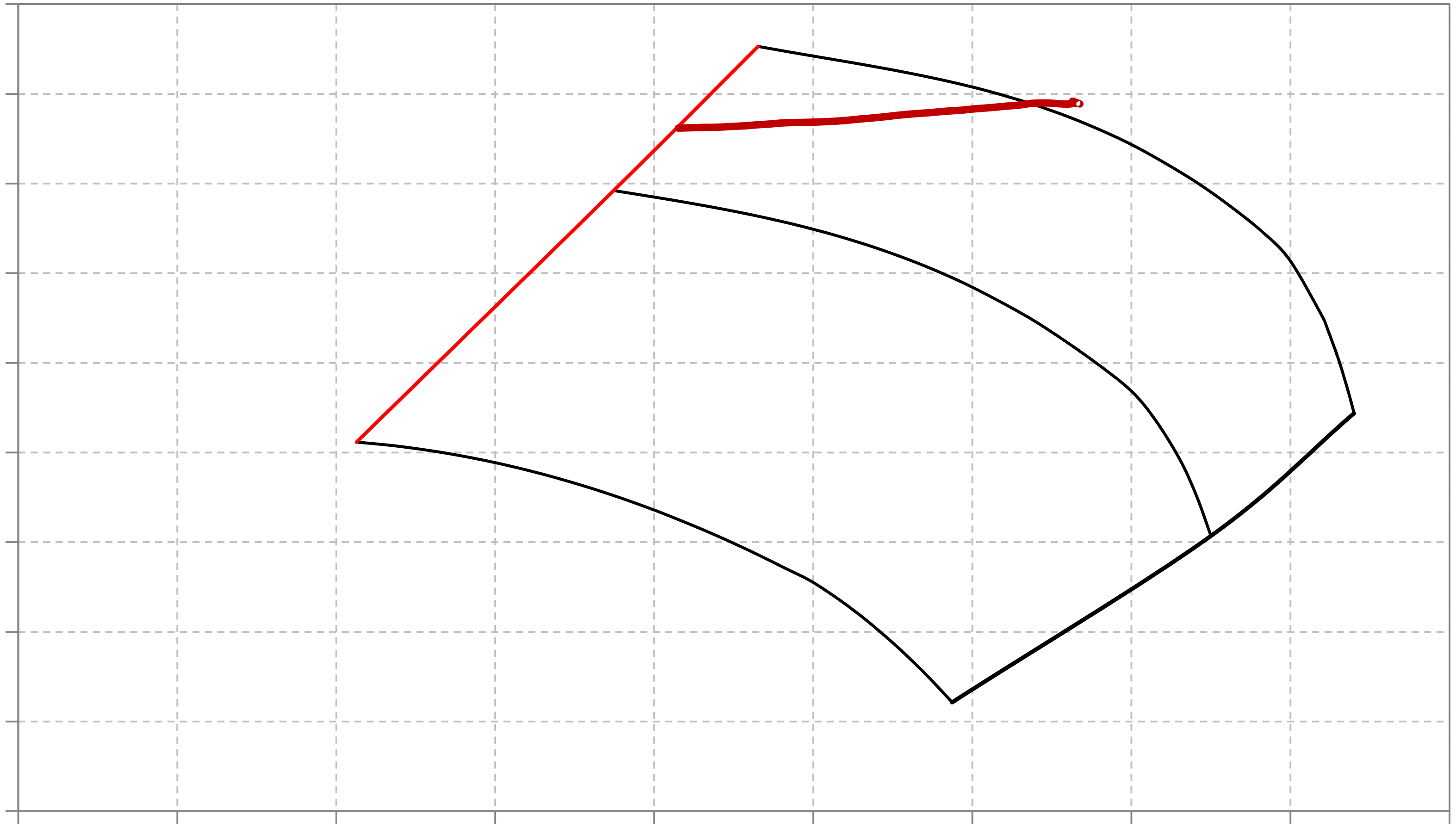
Coast-Down Delay & Hot-Bypass

- The surge avoidance was found to be better with a coast down delay of 0.75 seconds and a second stage hot bypass valve of 4-inch



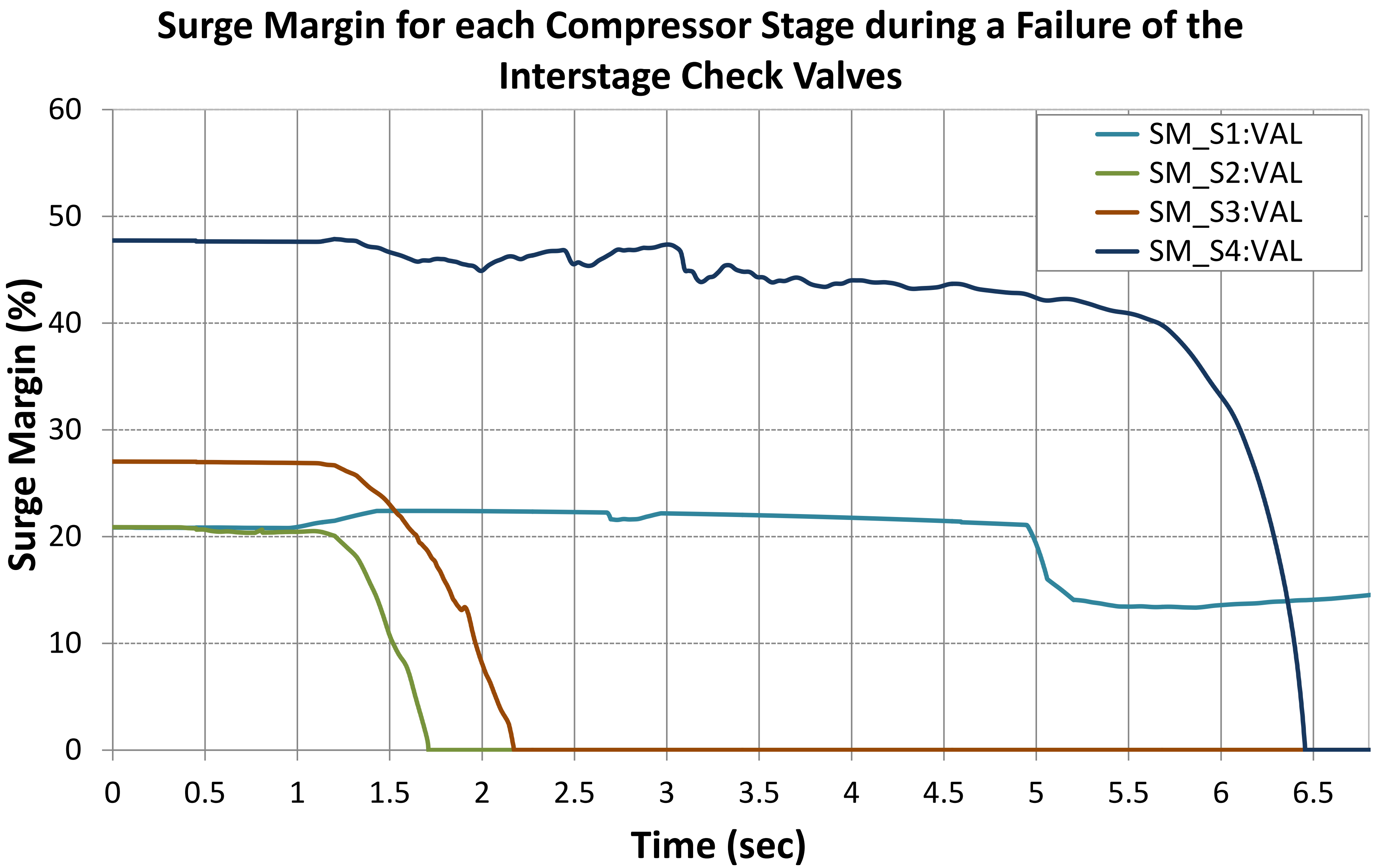
Different Sequences

- Use of 6 and 3-inch quick opening valves with 1.2 and 1.5 seconds on second and third stages is recommended



Blowdown and NRVs Effect

- A failure of the check valves during an ESD event made three compressor stages surged



Summary & Conclusions

- Parametric studies of the main variables are very important to determine the correct path of suitable modifications for complex systems such as multistage compressors
- The dynamic interaction between the stages and their anti-surge loop can be modified by properly adjusting the anti-surge logic and sequences
- Initial dH/dQ (pressure wave) behavior of each compressor stage is affected by the changes made in the entire train
- The impedance of the system will affect the initial reaction of the pressure waves originated when the machine is shutdown
- The system dynamics is very sensitive to changes since minor modifications in one stage will affect the transient behavior of the neighboring stages

Thank you for your attention!

I will be happy to address any questions.

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