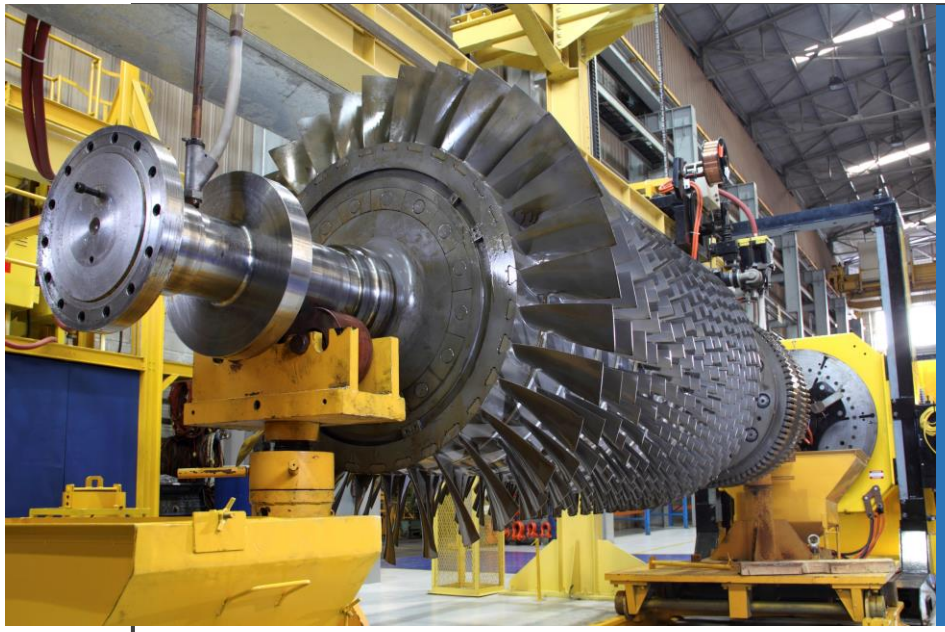


S&C Compressor Surge Prevention Control Solution

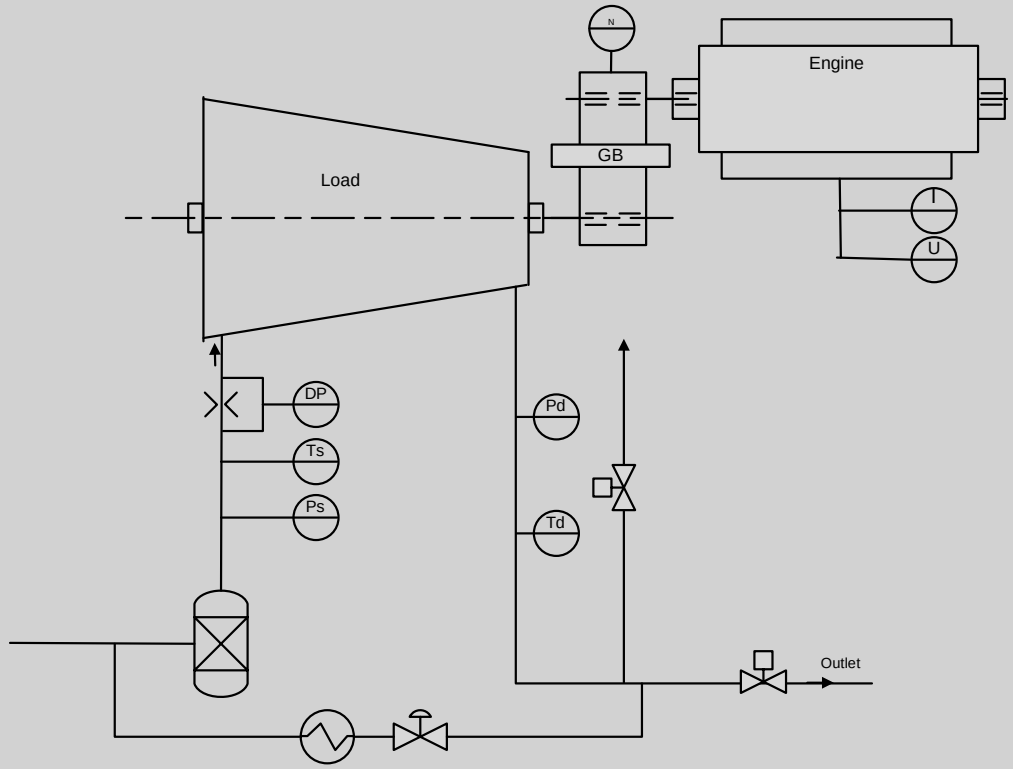
(Patent # US 10,254,719)

Turbomachinery Control Solutions Overview

Solutions for all variations of turbomachinery equipment

- Steam Turbine & Extraction Control
- Surge Prevention Control
- Gas Turbine Control
- Reciprocating Unit Control
- Compressor Group Station Control
- Power Generation Unit and Station Control

Solutions for all third-party hardware & software platforms compliant with IEC 61131



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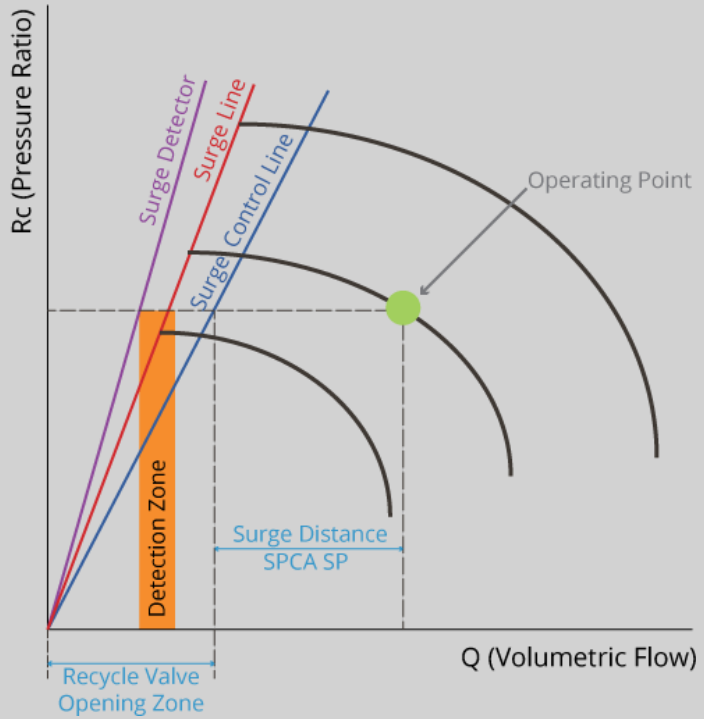
Surge Prevention Control

Surge Prevention Control Application (SPCA)

- Controls gas flow through compressor
- Defines the surge line and other operating lines over a wide range of changing conditions
- Uses two levels of PID control to operate surge control valve
- Calibrated using manufacturer specification and compressor maps or through field testing

Benefits

- Simplify calibration by recording surge events and conditions and by automatically defining parameters
- Balance surge control valve opening and closing to avoid surge but not waste power
- Use algorithms to determine how the surge limit changes as the process conditions change



$$k_{su} = \frac{(R_{csu}^{\sigma} - 1)}{\sigma} * \frac{P_{ssu}}{dP_{ssu}}$$

$$SP_{su} = dP_{ssu} * CLM = \frac{(R_c^{\sigma} - 1)}{\sigma} * \frac{Ps}{k_{su}} * CLM$$

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Multistage Compressor Applications

Ethylene Plant:

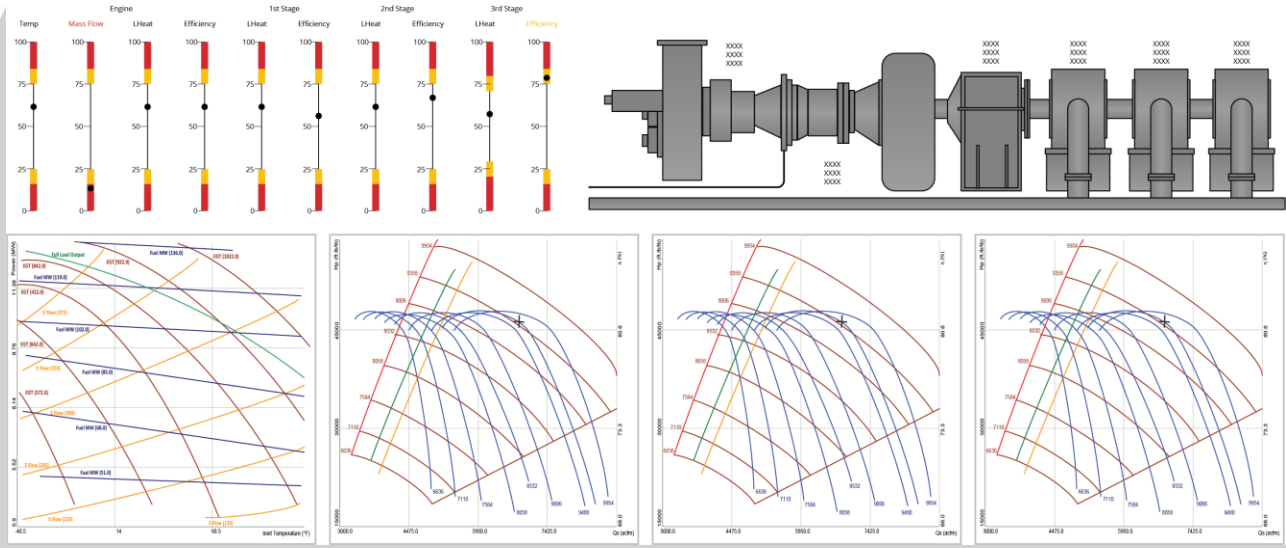
- Cracked gas compressor train, 4 or 5 stages, two recycle lines, driven by extraction turbine
- Propylene refrigerant compressor train, 4 sections with side streams, driven by steam turbine
- Ethylene refrigerant compressor train, 3 sections with side streams, driven by steam turbine

Urea Plant:

- CO2 Compressor train, 4 stages, one recycle lines, driven by extraction turbine

Ammonia Plant:

- Process Air Compressor. 2 or 3 stages, one blow off valve, usually driven by condensing turbine or an electric motor
- Syn Gas Compressor, 4 or 5 stages, driver is a steam turbine
- Ammonia Refrigeration Compressor, 2 or 3, driven by extraction turbine



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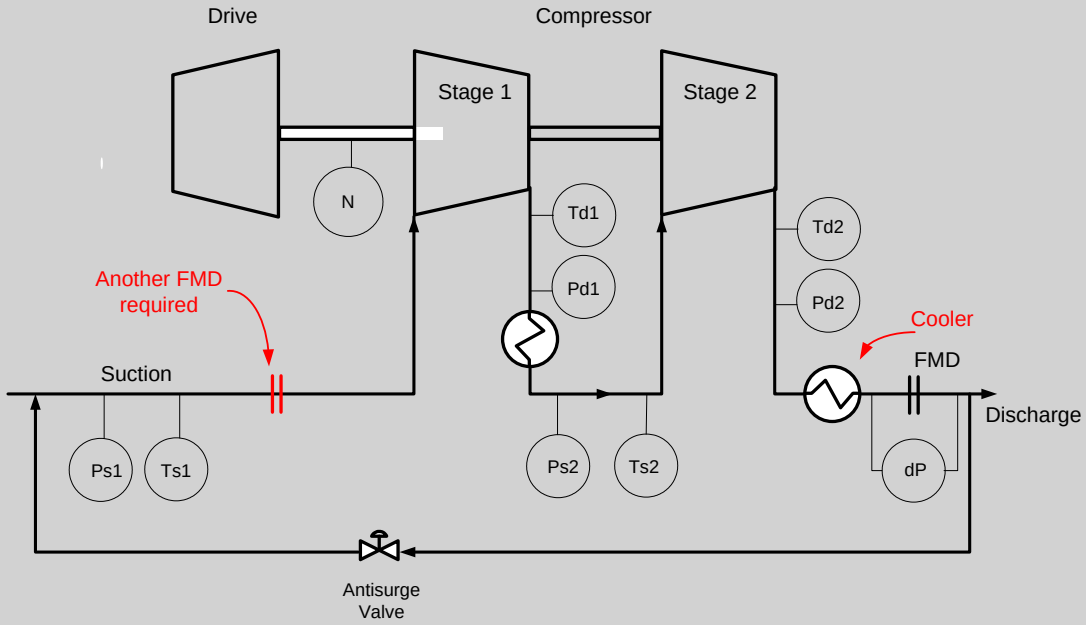
Traditional Control Design Problems

Typical Situation:

- One FMD per unit
- Cooler between FMD and compressor stage
- One recycle valve per unit
- Multiple Surge Controllers

Typical Problems:

- Inaccurate surge limit calculation for each stage
- Large surge safety margin
- No adequate surge protection



Traditional approach requests that a cooler should not exist between the flow element and the compressor stage it services

Traditional approach requests the flow element must be provided for each compression stage protected by an antisurge controller

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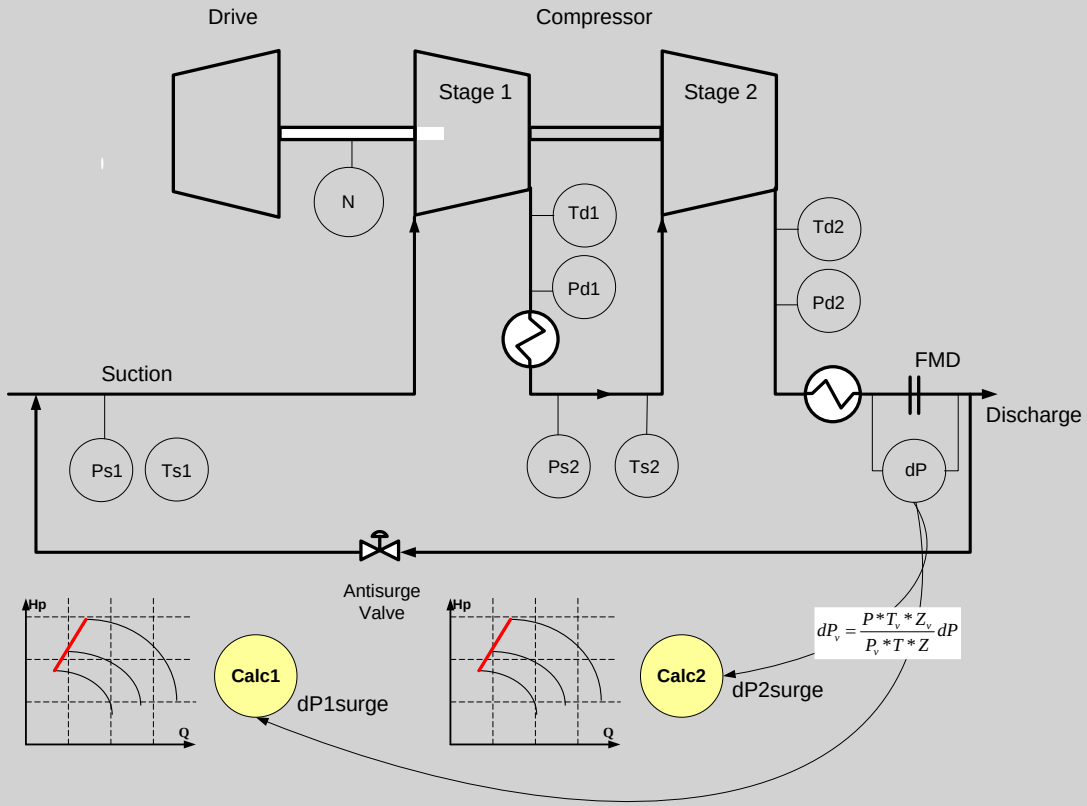
S&C Algorithm, Step 1

S&C method accurately calculates of surge limit line for overall multistage compressor using one available flow measuring device:

- If flow measuring device is not located in suction of compressor stage first algorithm converts flow to suction condition. It calculates virtual flow measurements for stages with no FMD.
- Each stage calculation algorithm is calibrated using manufacturer specification and compressor maps or through field testing. Surge limit line of each stage is computed via one available FMD.



$$k_{suv} = \frac{1}{dP_{ssu}} * \frac{P_v^{\,2} * T_{ssu} * Z_{ssu}}{P_{ssu} * T_v * Z_v} * \frac{R_{csu}^{\sigma} - 1}{\sigma}$$

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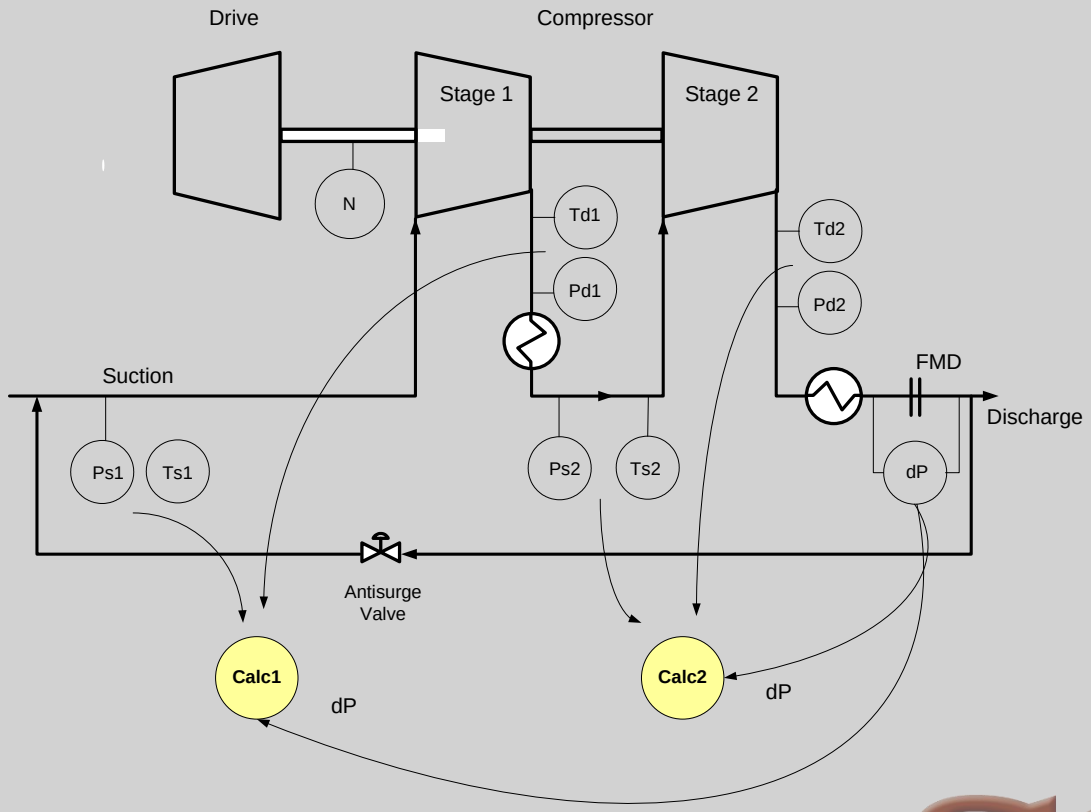
S&C Algorithm, Step 2

- Controller measures pressure suction, pressure discharge, temperature suction, temperature discharge, and speed for each stage.
- Each stage differential pressure surge limit set point calculated for current operating conditions as a function of calibration and current measured pressures and temperatures.



$$dP_{ssui} = \frac{1}{k_{suv}} * \frac{P_v^{\,2} * T * Z}{P * T_v * Z_v} * \frac{R_{ci}^{\sigma} - 1}{\sigma}$$

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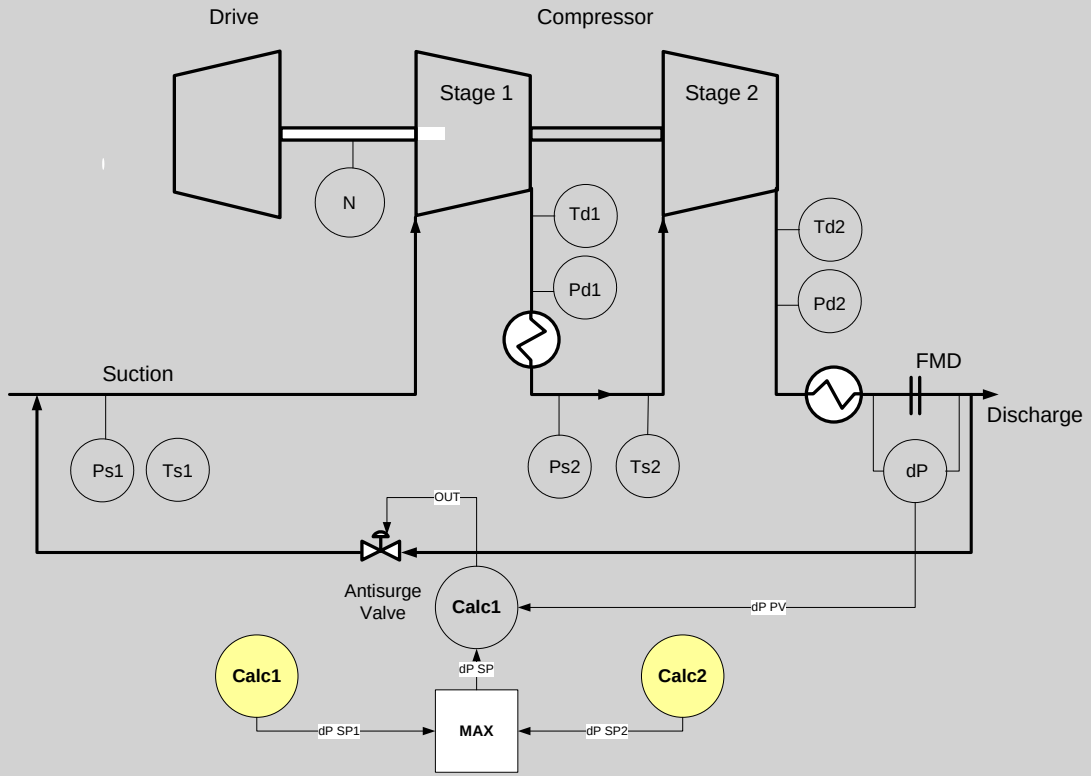
S&C Algorithm, Step 3

This method focuses on reliable Surge Prevention control of entire multistage compressor while simplifying the control system configuration and minimizing interaction between control modules.

- Controller computes overall compressor surge limit set point for current operating conditions by selecting maximal value of all computed individual stages surge limit set points.
- PID controller comperes current measured dP with computed overall compressor surge limit set point and modulating antisurge control valve based on comparison for compressor surge prevention.



$$dP_{sp} = MAX\,(dP_{spi})$$

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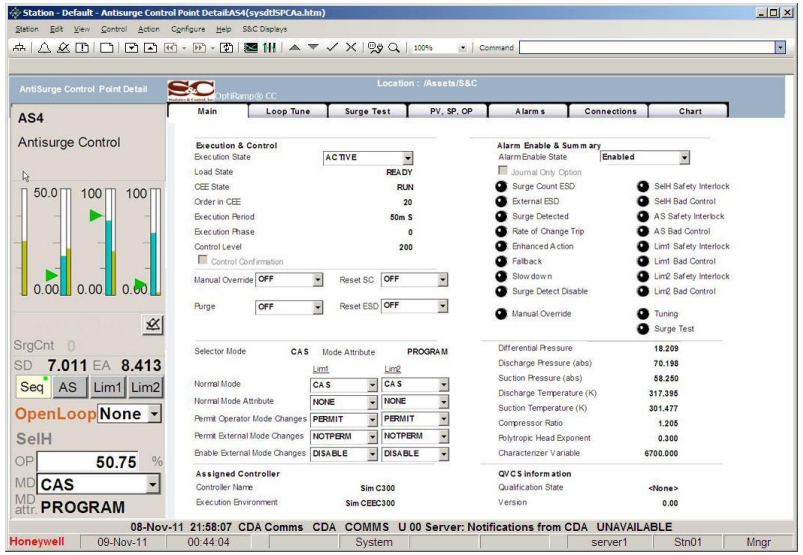
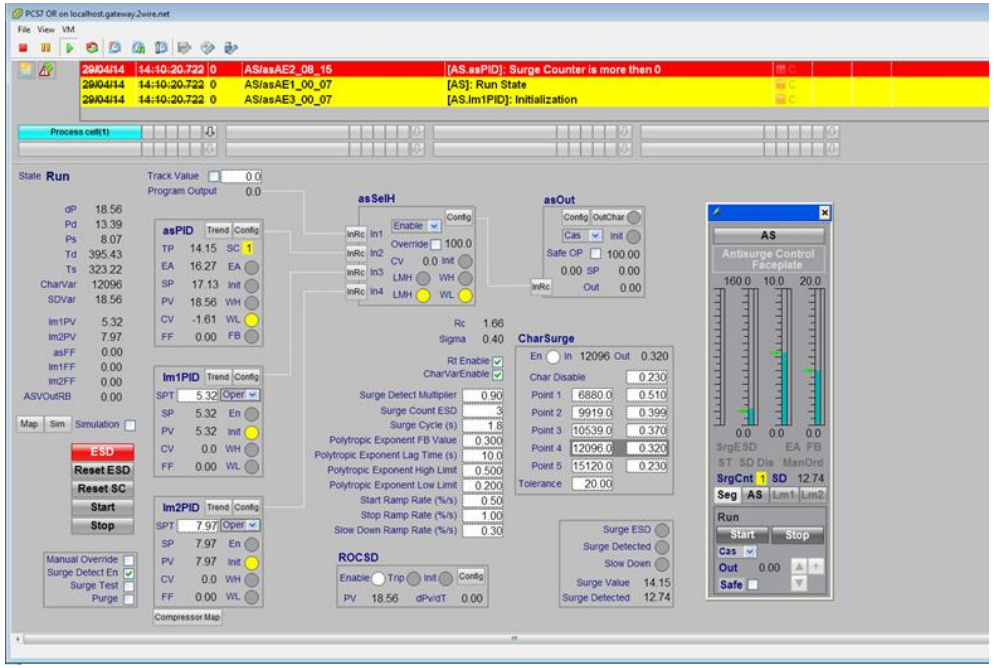
Hardware and Software Independent Control Platform

Now you can control your rotating equipment with the same control platform as the plant with tested, flexible, and competitive solutions and reduce support and maintenance costs





Benefits

Process Control

- Increased process reliability
- Reduced start-up time
- Reduced product waste
- Improved process control
- Reduced energy consumption
- Improved stability
- Reduced maintenance cost
- Reduced capital cost

Unit Control System

- Improved surge protection
- Larger operating envelope without recycle
- Optimum control during start-up
- Single supplier solution
- OEM neutral
- Hardware and software independent control platform
- Integrated compressor and turbine control system