Compressor Surge Prevention Control implemented on Yokogawa Stardom

Introduction

Continuous Control Solutions ("CCS") specializes in industrial turbo-machinery control challenges for various types of industries. CCS' turbo-machinery technology and patented control algorithms are hardware platform independent and have been successfully implemented on different hardware platforms since 2004.

Due to the variety of control platforms on the market, it is CCS's goal to offer robust, sophisticated and unified applications and algorithms developed and implemented on leading PLC and DCS systems. The requirements of a sophisticated turbo-machinery control system include having the capability to be programmed utilizing IEC-61131 compliant programming languages, availability of frequency I/O modules, etc.

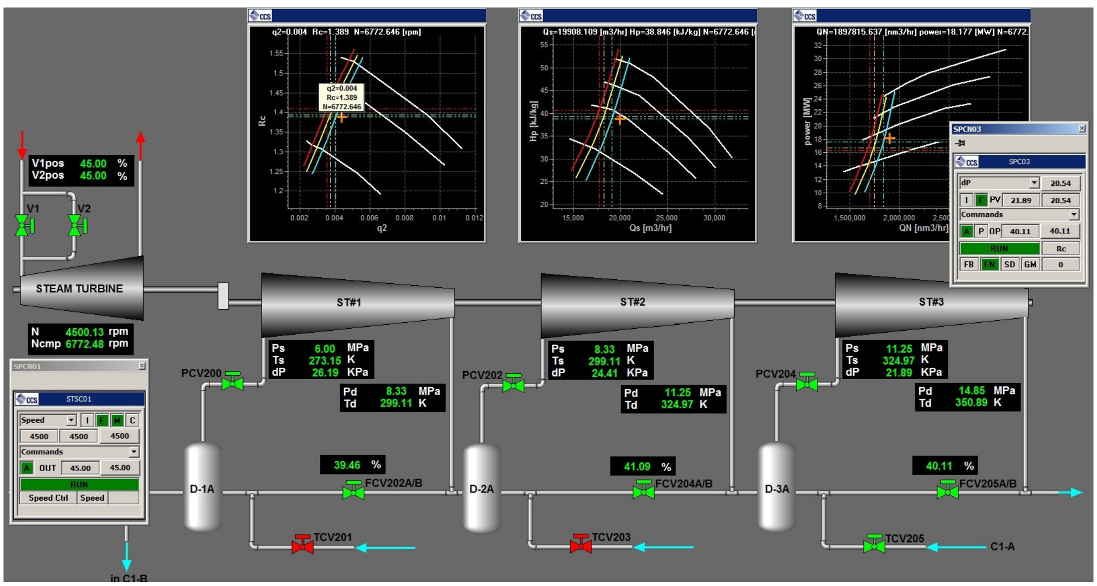

Figure 1: Three Stage Compressor with Steam Turbine

With Yokogawa's release of a newer controller NFCP100-S00, input/output module NGP813-S10 for turbo-machinery control systems and output module NFAI841-S00, CCS finally has the opportunity to implement its fully-functional, patented and world-proven algorithms within Yokogawa's Stardom PLC.

Surge Control Strategy

CCS's patented SPC provides two independent control loops - dP and Rc. During normal operations, CCS systems offer a High-Select mode and control based on the most efficient variable. If at any point in the process either measurement becomes unavailable, the System provides true continuous control by automatically controlling based on the available control loop.

The SPC has two Surge Prevention Control PID loops. One of them controls the surge distance along Rc-coordinate, another along dP-coordinate. The set points for these loops are calculated using CCS's proprietary Control Safety Margin (CSM) algorithm. When Surge Line is determined, CCS field engineer sets the CSM values for both Rc- and dP-coordinates. This defines the distances to the Surge Line which need to be maintained by the control loops.

The surge prevention controller (Figure 2) uses first closed loop PID module to control the operating point of the compressor below pressure ratio at surge limit conditions (Rc_s) set point for current speed. The process variable of the PID control module is current pressure ratio (Rc). The PID loop generates a control signal for controlling the opening of the antisurge valve. A surge limit line is positioned in the stable operating region and displaced down by the safety margin. The suggested size of the safety margin is typically 3-5% of Rc span and covers the inaccuracy of 1% on polytropic exponent (σ).

When the flow measuring device is available, the SPC uses the second closed loop PID module to control operating point of the compressor to the right side of the flow rate at surge limit conditions (dPo_s) set point for current speed. The process variable of the PID control

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module is the current flow rate (dPo). The PID loop generates a control signal to control the opening of the anti-surge valve. A surge limit line is positioned in the stable operating region and displaced to the right by the safety margin. The suggested size of the safety margin is approximately 3-5% of the dPo span.

The two control signals generated by each respective control loop are fed to a "high selection" algorithm that drives the opening of the antisurge valve.

These techniques are applicable to axial and centrifugal compressors with variable speed or guide vanes.

Such a system is especially effective for surge prevention controllers of multi-stage compressors and compressors with side streams where not all of the necessary flow measuring devices are available.

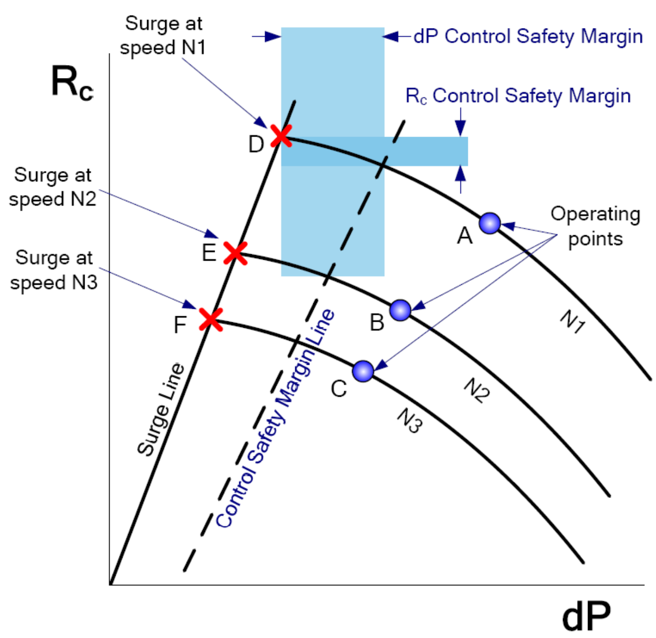

Figure 2: Surge Prevention Control

Features

- **Surge Control** - SPC provides fully integrated multi-loop, multiple-body compressor surge control. More efficient compressor operation is provided by eliminating unnecessary recycle.
- **Surge Detection** - with CCS detection rate-of-change method surge of the compressor can be stopped during the first cycle by opening of the recycle valve and surge control line is moved to pre-selected position.
- **Simplified controller calibration** - to calibrate the surge limit line, one or several surge tests have to be carried out. For variable speed compressors and/or compressors with inlet guide vanes the surge test should be performed at several speeds or guide vane positions. Or, it can be calculated mathematically based on theoretical compressor map provided by compressor manufacturer. SPC controller then automatically linearly interpolates surge points.

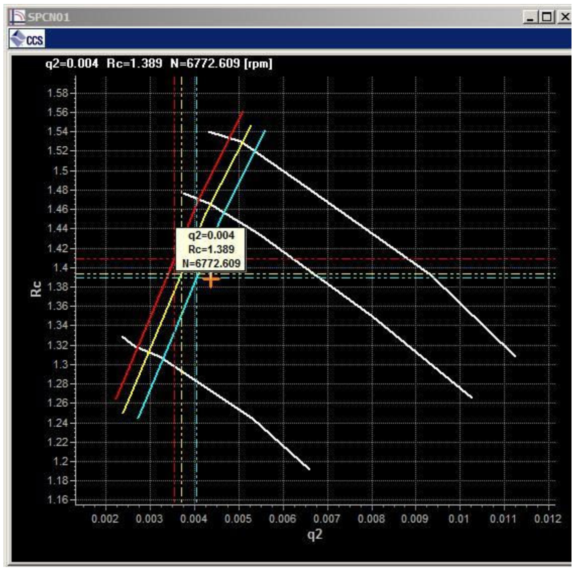

Figure 3: Compressor Map

- **Derivative Algorithm** - derivative control actions as given in a conventional PID controller, under normal compressor operating conditions, would tend to make the system unstable and therefore not used. However, for some fast changing conditions, the normal PI control response is not sufficient to prevent flow from decreasing to values less than the control line. In general, the controller is slow for normal operating conditions, but fast when needed to protect the compressor from surge. During rapid decreases in flow near the surge control line, Derivative control algorithm opens the surge valve before the operating point reaches the control line. Normal PI control resumes when the process upset stabilizes.

- **Variable Gain Safety Margin** - the Variable Gain Safety line (Figure 3) is located between the surge line and the control line and provides a basis for additional control action. If the operating point of the compressor decreases to flow values less than those defined by the Variable Gain Safety line, traditional PI control is enhanced by the Variable Proportional Gain control function to facilitate rapid opening of the surge valve. The output to the valve increases with increased gain thus opening the surge valve much quicker than possible with conventional PI control. Valve opening continues until the flow has moved to a safe level. Using increased gain factor avoids compressor surge, minimizing the effects of process upsets.

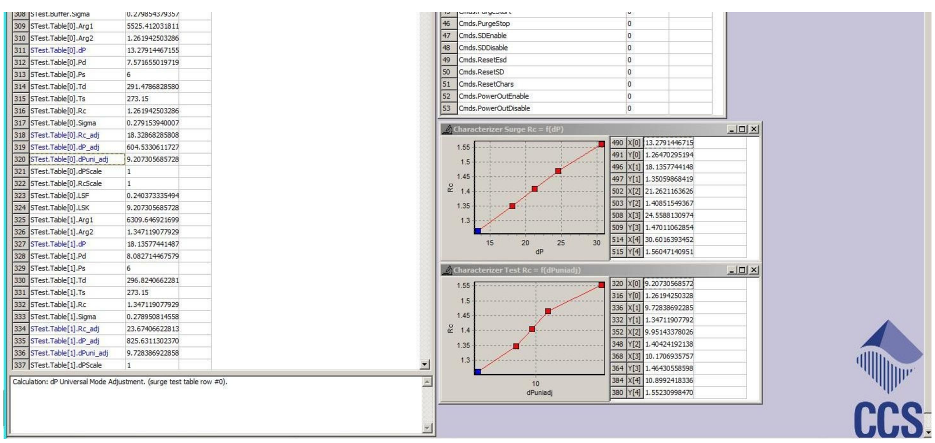

Figure 4: SPC Configurator

- **Limiting Control** - SPC includes additional control loop to limit the discharge or suction pressure by increasing recycle rate.

- **Fallback Algorithms** - allows for continued, safe operation in the event of transmitter failure. Even when a flow sensing transmitter fails the controller will continue to operate in automatic mode using pressure ratio control.

- **Start-up and Shutdown Modes** - SPC includes additional algorithms to provide for start-up and shutdown mode of the compressor in accordance with the compressor manufacturer's specifications and in compliance with process requirements.

Steam Turbine Speed Control Strategy

CCS' Steam Turbine Speed Controller (STSC) enables fully automated speed control during normal operation as well as startup/shutdown speed control including critical speed avoidance. It provides for a versatile and economical way to regulate a steam turbine's speed or power, protect against overspeed damage and automatically sequence startups and shutdowns. Its redundant inputs, fault detection and fallback strategies features define a new, more economical approach to fault tolerance for such machines. In general, it controls an industrial steam turbine efficiently and reliably.

Speed control provides the primary method of controlling the speed of the turbine comparing the three speed signals with the speed set point. This comparison generates an error term, which is used to generate the control output. The control output is "low selected" with the output of the valve ramp function and the auxiliary loop function to obtain the value for the valve output function.

Features

- **Speed/Load Control** – Steam Turbine Speed Control application provides isochronous control mode with selectable local, remote, and cascade set points to maintain speed. Isochronous control is used for variable-speed loads (such as compressors). Each

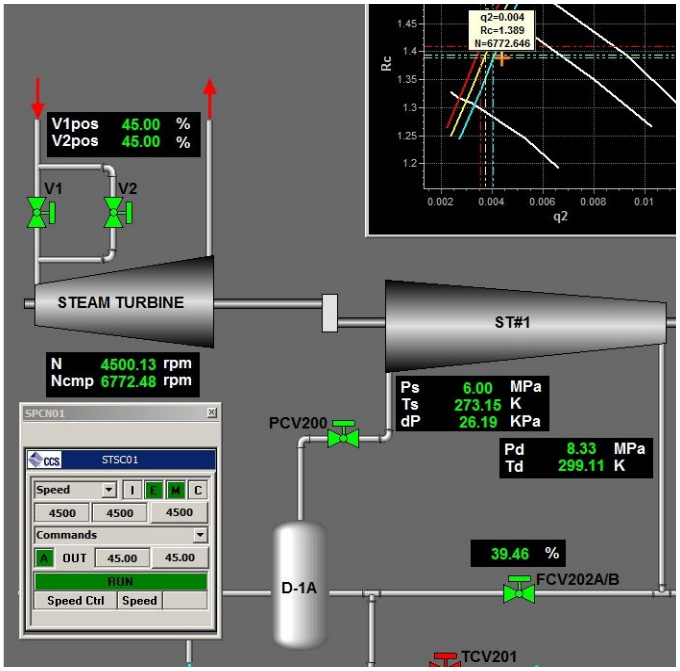

Figure 5: STSC Operator Screen

mode adjusts to changing system dynamics by varying its gain and reset rate as functions of the speed or steam flow rate. Steam Turbine Speed Controller provides several features that prevent critical and overspeed damage to the turbine and driven unit. In addition, because the overspeed features remain in effect even during manual operation, the equipment is assured of uninterrupted protection.

Other tasks include:

- Load Rejection Protection;
- Flow Characterization;
- Pre-warming;
- Protective System Testing;
- Over-speed Protection;
- Valve Testing.

- **Configurability** - STSC is fully configurable to any industrial steam turbine and will meet all OEM operational and control specifications.
- **Train Control Systems** - STSC is typically integrated into the train control system. This integration results in increased train control system availability and reliability.
- **Fallback Algorithms** - Fallback Algorithms allow for continued safe operation in the event of speed transmitter failure through voting.
- **Startup and Shutdown Sequencing** - STSC includes configurable algorithms providing automated startup and shutdown sequencing of the turbine in accordance with the manufacturer's specifications (including avoidance of operation in critical speed range) and in compliance with the process requirements.

Test Results

CCS has conducted a variety of tests upon the completion of the development of its Surge Prevention Control and Steam Turbine Speed Control applications for Yokogawa Stardom. All CCS control applications were loaded to a dedicated controller NFCP100-S00 along with CCS's turbo-machinery simulation software. The following system performance results were obtained:

Table 1. Module NGP813-S10 signal processing speed.

Signal type	System response time [ms]	
	Min.	Max.
Frequency signal	32	36
Analog signal	22	30
Discrete signal	10	18

Table 2. Control system rate of response to signal change (without STSC).

Signal type	System response time [ms]			
	Task execution cycle 20ms		Task execution cycle 40ms	
	Min.	Max.	Min.	Max.
Frequency signal	36	48	36	60
Analog signal	48	56	44	72
Discrete signal	30	54	56	68

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Table 3. Control system rate of response to signal change (with STSC).

Signal type	System response time [ms]			
	Task execution cycle 20ms		Task execution cycle 40ms	
	Min.	Max.	Min.	Max.
Frequency signal	62	80	48	80
Analog signal	42	54	60	78
Discrete signal	40	56	44	72

The comparison of the above tables 2 and 3 clearly shows that the system response time depends on the complexity of the program, executed by the processor. See Table 4 containing the results obtained in the test. A frequency signal only was used as based on the above comparison, increasing in response time does not depend on type of signal.

Table 4. System response time with maximum CPU load.

Signal type	System response time [ms]	
	Min.	Max.
Frequency signal	64	132

Conclusion

The performance of the system, which was determined during tests, is sufficient to build reliable and robust control systems for any types of turbo-machinery equipment. Some types of machines require a high performance control system. Such applications include aero-derivative and marine gas turbines and, in some cases, steam and gas turbines used in power generation. The Yokogawa Stardom controllers can be used for these applications, however some stipulations should be considered. For most of the "fast" machines, the time from the unload event to the complete closure of the fuel or steam valve should be no more than 0.5-0.6 sec. The "extra" 80-90ms of the time lags of the electronics would be absolutely undesirable in these cases. One needs to keep in mind that in such event, the actual system response time will be longer because the logic program will not generate a shutdown signal during first or second scan after the event. Therefore, in such “fast” applications the Yokogawa Stardom controllers cannot be used for implementation of the functions of the rotor overspeed protection within STSC (Steam Turbine Speed Controller) and GTFC (Gas Turbine Fuel Controller). However, it is not a serious limitation of system utilization, as in most projects, a dedicated electronic turbine overspeed protection unit is typically provided by manufacturer or third party. For other types of turbo-machinery equipment, such as axial and centrifugal compressors, industrial steam and gas turbines, extra heavy-loaded turbines and general purpose turbine, etc., the system performance does not give rise to any objections. The system’s "screw to screw" response time of up to 100ms is more than enough for such "normal" applications. It should also be assumed that time lags of the actuating devices (typically valve positioners) will be within 150-300ms anyway. In any case, it is 2-4 times more than time lags of the speed controller’s electronics. Thus such a system will be capable to provide an adequate control for most turbo-machinery equipment.

Using of module NGP813 as a safety overspeed protection unit is clearly possible as far as the response speed is concerned (“screw to screw" response is no more than 36ms), provided it has all appropriate permits and certificates.

Remarks

During tender process customers sometimes ask to fill out a table with various technical data, namely:

- "generating/sampling time of analog/digital output signals"
- "read time of frequency/analog/digital input signals"
- "scan time (reading data from input cards) of input signals"
- "controller’s execution time of the logic program "

In some cases performance demonstrated by Yokogawa Stardom controller during tests may be higher than in other competitive systems. Therefore, despite the positive test results of the system, one needs to be prepared to reasonably answer the questions from customers and, in case of certain concerns and requirements, be ready to upgrade the system.

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