Expertise in Turbomachinery Controls

WHITEPAPER

When Safety Systems Add Risk

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Mohamed Mostafa and Shreef Elaraby, CCC, Saudi Arabia, emphasis on the critical importance of safety in an industry motivated by growth and cost reductions.

Introduction

Plant and process engineers today are facing heightened pressure to continually improve performance that contributes additional value to the company's bottom line. To continually meet these performance goals, turbomachinery trains must remain online and run at a capacity that approaches operating limits, all while avoiding process upsets and machine trips. While these higher workloads increase outputs, the safety risk to machines, personnel, and operations is also increased.

These performance requirements and heightened operating risks place a greater burden on engineers to select a safe, reliable system that improves process operations to control their machines. Industry safety standard requirements such as IEC61508/511 can contribute additional complexity to the decision-making process when selecting a control system.

To minimize operational risk and maximize uptime, some vendors offer solutions renowned throughout the industry for safety, availability, and security while using a SIL rated safety system. While these emergency shutdown systems (ESDs) offer a simpler diagnostic interface, these systems sacrifice process efficiency to achieve high reliability and if not implemented according the SIL certification guidelines these systems are not more reliable than build for purpose control systems.

Assessing the Existing Environment

A petrochemical plant in the Middle East, who was using a SIL-3 rated ESD system, began noticing irregularities with their CO compressor and brought in a trusted consultant to perform an on-site audit. During the audit, consultants discussed issues the petrochem team observed, and key compressor and instrument data was collected.

Following the audit of the CO, CO_2, and NG compressors, transmitters, flow elements, impulse lines, and antisurge valves, inefficiencies were found with hardware components and their compressor control strategy. Those inefficiencies included excess energy waste of over $524,000 (USD) annually.

In addition, due to the poor control strategy of the existing system, an uncoordinated control response would create process instabilities and trip the machine, resulting in a production loss and increased safety exposure. This exemplifies a situation in which using a safety system with poor control algorithms increased safety risk.

Following the study, CCC recommended that the petrochemical plant redesign their existing compressor control strategy with a more integrated control philosophy for antisurge and performance controls. By making these adjustments, the plant would be able to eliminate drawbacks of the old safety system that led to increased compressor recycle rates and increased electric and steam consumption.

The first step to a more efficient process was to make the necessary adjustments to piping configurations and transmitter specifications and locations. Secondly, we integrated the performance (capacity) control with the antisurge control to avoid loop interactions and ensure smooth coordinated control between the control loops. This eliminated the trips caused by the loop interactions. Lastly, we recommended surge testing for all machines to improve machine safety and to obtain a more accurate operating margin for all compressors to increase overall production of the plant.

Analyzing Findings

For a turbomachinery control system to run efficiently, all hardware components, including transmitters, valves, piping, and algorithms, must be properly tuned to prevent inaccurate measurements. When all components are integrated with each other, processes run more efficiently and the turbomachinery control system is more accurate.

The petrochemical plant was utilizing both flow and pressure transmitters to monitor key process variables and relay information to the control system, but their location (below tapping points) made them more susceptible to condensate build-up. They were also set to a linear output with a damping of 0.4 seconds. For accurate outputs it is recommended that flow transmitters have a response time of less than 0.2 seconds. Some transmitters were equipped with a relatively long impulse tubing (>20 meter), which introduced a time delay. Tubing length should be kept to a minimum to improve transmitter response time.

Transmitters play a crucial role towards efficient operation. Four key characteristics of transmitter applications include: accuracy, precision, signal-to-noise ratio, and response time. If the placement of transmitters is incorrect, the accuracy and precision is greatly reduced, which can lead to a slow response time to the antisurge valve, causing the valve to be open more than necessary.

For different stages along the CO compressor, discharge pressure transmitters were located downstream of the coolers and downstream of the recycle line takeoff. This did not provide accurate discharge pressure measurements and led to an increased discharge volume. Large discharge volumes significantly decrease the effectiveness of antisurge protection.

Good instrumentation design practice dictates that all flow and pressure transmitters are installed above tapping points with short, sloped impulse lines, avoid any condensation buildup. Mounting transmitters in this fashion allows for proper performance. By optimizing transmitter location, the antisurge controller has more accurate compressor discharge pressures for various stages, which leads to faster response times and a more efficient usage of the antisurge valve.

Implementing The Solution

The existing system did not allow for coordinated control loop responses between different control loops acting on the same machine. Loop decoupling between capacity control loops and antisurge control loops reduce instability and promote a smooth process control, when process disturbances occur, however this wasn't available with their old system.

Control loop decoupling is normally implemented among controllers with control loops that interact with one another. During decoupling, a controller will inform its companion controllers of its intended change in outputs, resulting in smoother process control and enhanced antisurge control. When a lack of decoupling is observed, we recommend fully integrating antisurge and control loop decoupling to ensure coordinated control loop response.

The old antisurge controller was using variant coordinates to define the surge control line (SLL). Using variant coordinates is not suitable for surge protection. When compressor suction conditions or gas compositions are slightly changed during operation, the configured SLL is no longer valid. When surge limit lines lose validity and accuracy, machines are put at a higher surge risk.

To better define the SLL, we highly recommend using invariant coordinates, simply because they are not affected when compressor suction conditions or gas compositions change. With invariant coordinates, the compressor is protected from surge during a variety of different operating conditions – increasing the compressor's safety. Figure-1 compares the surge limit lines using variant coordinates with the same data using invariant coordinates.

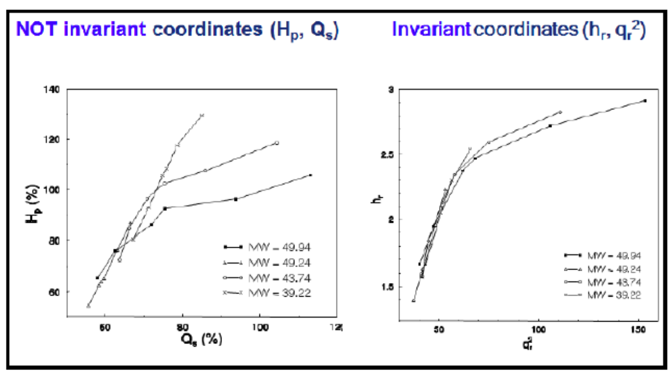

Figure-1 A comparison of variant vs. invariant Surge Limit Lines on the same machine at the same flow and pressure rates

To accurately determine a compressor's SLL, a surge test must be completed. Original equipment manufacturers (OEMs) have factory established surge conditions, but those conditions will differ during actual operation based on a variety of factors, including: elevation, climate, machine age, and materials used in production.

As a commissioning requirement of the control system, surge tests will be conducted to test whether the OEM defined SLL is the actual machine's SLL. This testing protects the compressor from surge and widens operating envelopes. If a compressor is not surge tested, the turbomachinery control system may not be able to provide the data necessary for safe, efficient operation.

Due to the risks involved, surge testing should be done by highly qualified and experienced personnel and vendors. Based on the criticality and significance, surge testing should be a requirement for all compressors during commissioning. It can extend the lifecycle of machines and improve process efficiency, but more importantly, surge testing is another measure to protect the safety of all plant employees.

Following surge testing at the plant, the audit found the SLLs for all three compressors were set too conservatively due to an inadequate tuning of the antisurge control system algorithm. Contributing to the poor tuning were the use of variant coordinates for compressor mapping and improper locations of surge limit lines.

A conservative SLL minimizes available compressor operating margins. When margins are decreased, the recycle valve opens before the operating point reaches the actual SLL. Excess gas recycle is introduced due to the unnecessary openings of antisurge valves, and as a result, a unit's power consumption exceeds the necessary process power demands. The only way to accurately determine if SLLs are set to conservatively is to perform an on-site surge test.

For the plant's NG compressor, the actual SLL was located to the left of the old control system's SLL. By performing a surge test, analyzing the data, and moving the SLL closer to the actual surge limit line, operating margins were increased (Figure-2). The shifting of the SLL also lowered compressor recycle rates, which reduced power consumption.

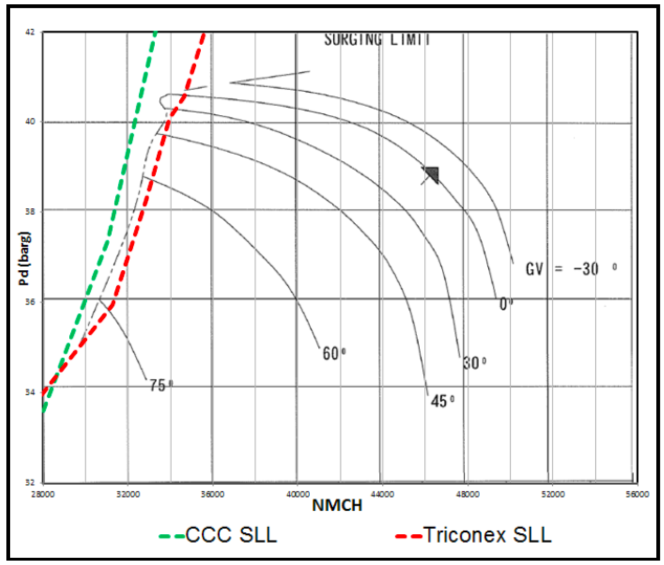

Figure-2 Compressor map of the SLL comparison for this company's NG compressor

In all three compressors, the post-surge test report showed protection margins that were set too conservatively due to the inadequate tuning of the antisurge control system algorithm. In this case, the use of variant coordinates for the CO compressor and improper locations of the surge limit lines. Excess gas recycle was introduced due to the unnecessary openings of antisurge valves, and as a result, the unit's power consumption exceeded the necessary process power demands.

By surge testing machines and redefining control algorithms, quicker response times and more accurate data contributes to a more accurate process. In Figure-3, the opening of the plant's antisurge valve is shown, both one month before with the old control system, and one month after with a more efficient system. Figure-4 shows the corresponding energy usage during the same time frame.

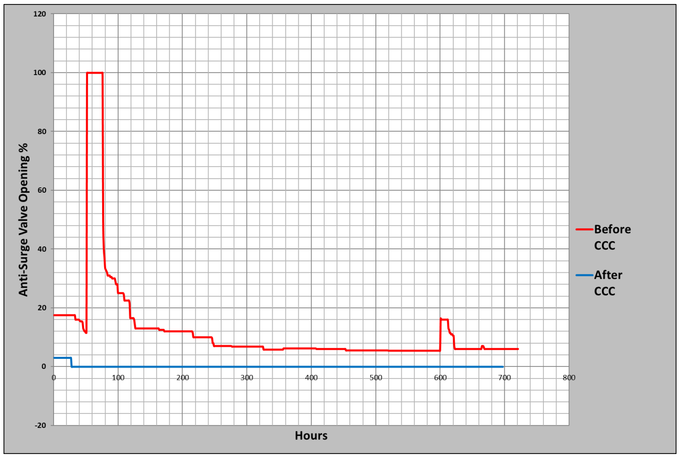

Figure-3 Comparison of antisurge valve openings for the CO2 compressor with a reliable ESD system (in red) vs. an efficient control system (in blue)

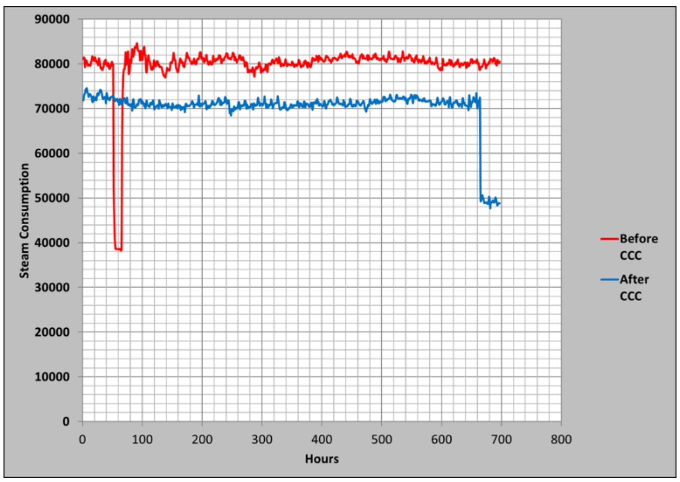

Figure-4 Comparison of steam consumption the CO compressor during the same time span of figure 3. Reliable ESD system (in red) vs. an efficient control system (in blue).

Conclusion

Improved process performance does not have to come at the expense of reliability. Safety systems used with the intent of providing performance control will typically fall short of achieving high efficiencies and may fall short in delivering the intended safety protection. Using built-for-purpose control systems with invariant coordinates, loop decoupling, and proper surge testing, turbomachinery can be run at higher capacities while minimizing process upsets and machine trips.

About the Author:

Ahmed Adel, Account Manager at Compressor Controls Corporation, Saudi Arabia. Ahmed leads a joint company-strategic planning in Saudi Arabia that develops mutual performance objectives to provide technical guidance and support that best addresses Saudi Arabia customer needs and meets their requirements for efficient technical solutions. Ahmed received his B.S in Mechanical Engineering from Cairo University and he is a TÜV FS Engineer.