OCTAVE

WHITE PAPER

Are you in control of your control loops?

Contents

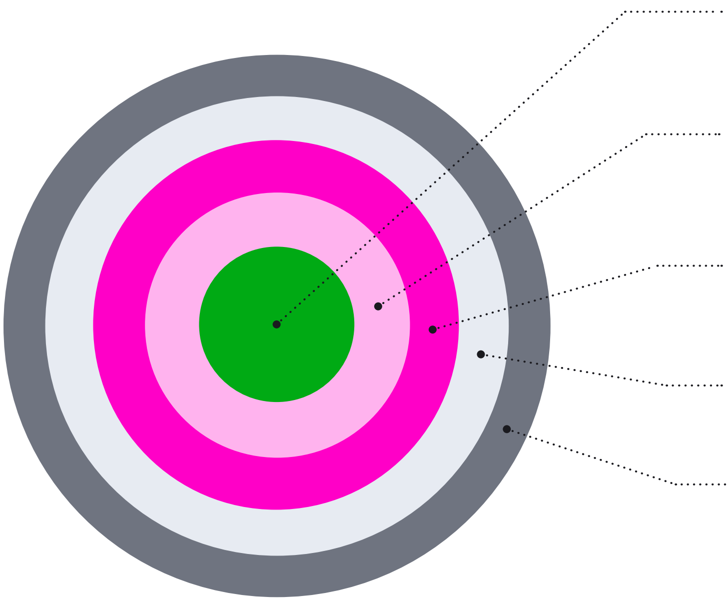
Executive summary

Operations risk management (ORM) is a layered approach designed to ensure safe and profitable operations. ORM focuses on the automation and control functions of process operations. Control loops are the first line of defense against risks to safety, the environment, production, efficiency and profitability.

Optimizing loop performance reduces risk in several ways. When control loops work properly, the process can achieve nameplate production rates, on-spec quality and maximum efficiency. Process upsets do not occur. Process intervention by the operator is needed less often, and mistakes in intervention are less likely. Safety systems have less need to activate. Shutdowns do not occur, helping reduce the most hazardous and risky step for most processes – the startup.

Optimizing the performance of regulatory controls requires knowledge of the process and control systems, the right tools for the job and following a systematic approach. In this paper, we'll discuss common reasons for poor control loop performance and a seven-step process to help your organization optimize control loops. Finally, three examples of successful control performance improvement initiatives are discussed.

Other lines of defense back up the control loops. This diagram shows them and are addressed in other white papers from Octave.



Alarm & operator intervention
Normal Ranges, disturbance rejection,
optimal settings

Effective operator intervention
operator situation awareness optimized:
Alarm system and HMI

Safety shutdown systems
Safety system performance, verification
and monitoring

Automation asset management of change
Elimination of unauthorized or inadvertent change

Risk monitoring and visualization
Monitor defenses in real time

Figure 1. Control loops are the first line of defense for operations risk management

The state of regulatory control in industry

Modern control systems are both sophisticated and complicated. A typical operating position may cover well over a thousand sensors, thousands of configured alarms and hundreds of controller elements. That is a high cognitive load even when the process is working normally. When many loops fail to achieve their intended purpose and must be run manually by the operator, then production, quality and efficiency will suffer and safety risks will increase.

Considering the importance of control loop performance, and the amount of money spent designing, purchasing and installing loops, their generally poor performance in the industry is shocking. Studies of thousands of loops over several years show:

- More than 30% of controllers are run in manual mode
- More than 30% of loops increase variability over manual control due to poor tuning and that is the reason operators place them in manual mode
- Approximately 15% of loops have design problems
- Approximately 30% of loops have equipment problems

Commonly discovered problems include:

- Sub-optimal controller tuning (77%)
- Incorrect valve size or flow characteristic (51%)
- Valve hysteresis (27%)
- Valve stiction (26%)
- Nonlinear process characteristic (18%)
- Large external disturbances (18%)
- Incorrect control strategy (15%)

Symptoms of poor loop performance include excessive process variation around a setpoint, cycling or oscillation or poor disturbance response. Disturbance response is the ability of the controls to bring the process back to a steady state after an outside influence or to accomplish a rate or value change smoothly and without overshoot and oscillation. Symptoms often show up in process history data – which is often not reviewed by anyone, unfortunately. In many cases, the resources that were responsible for maintaining control performance in the past have been centralized, downsized or lost to attrition as well.

With poor loop performance and increased process variability, key elements will need to be run further away from alarm setpoints and safety system trip points. Reduced process performance and profitability are inevitable. Addressing the problem proactively reverses Figure 2.

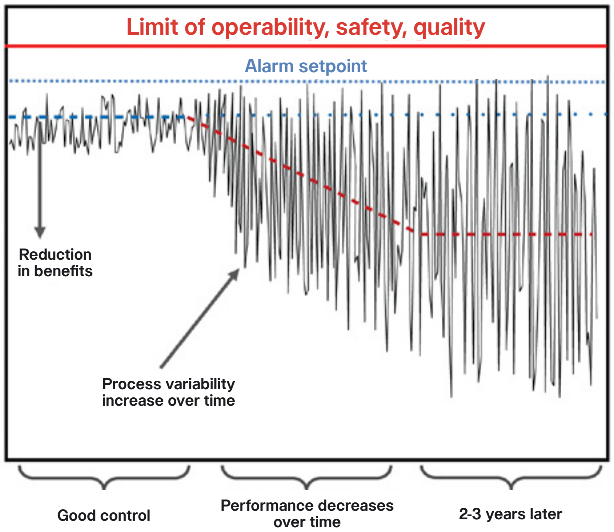


Figure 2. Increased variation reduces process capability

Optimizing regulatory control typically reduces raw material & energy costs by **2%** to **6%**.

Reasons for poor loop performance

The reasons for poorly performing loops are found in these three distinct areas:

Design practices

Loops are specified and configured during design. As controller points are "built" in a DCS configuration, the initial loop tuning coefficients are populated. These coefficients may be specifically entered based on experience with a similar loop or they may be just the default values provided by the DCS manufacturer. In the latter case, those default values are hardly ever optimal for a specific loop.

Commissioning deficiencies

Project commissioning and startup is a hectic time. In many cases, the schedule is full, production needs to catch up and the budget is exhausted. Loops that are found not to work in a significant way may be detected and addressed. But if the process basically runs, any optimization is often left for a later effort, and the project budget is closed.

Operations issues

Many loop problems will show up during the operations phase, not the relatively brief commissioning period. Typical razor-thin operations/maintenance budgets cannot usually support major improvement efforts. Engineering personnel are stretched thin. As a result, after years of operation, it is common to find hundreds of loops in a plant still carrying their default tuning coefficients. In other words, those loops have never been tuned at all.

Once operation begins, control valves begin to wear. A flow valve may experience 1 to 2 million reversals of direction in a year. Valve packing is likely to be over-tightened as part of an emissions control program, introducing stiction problems. The characteristics of the process may change with time, as heat exchangers foul, pump impellers wear and modifications are made. The operating strategy may change, going from "sold out" to "most efficient operation," which might require different control strategies for optimum performance. Once started, plants may run for their lifetime with sub-optimal control configurations. A plant may "limp along," becoming less reliable and profitable over time.

The question is not, "How do I justify improving my control loop performance?" The question is:

> What is my justification for tolerating poor loop performance?

Loop performance optimization using automation

Plants commonly make attempts to improve the performance of a control system in an ad-hoc fashion, mostly by adjusting controller settings of loops, which are clearly cycling or have poor response. Rarely is a systematic, comprehensive approach followed, so optimal results are also the exception rather than the norm. Important factors, such as control valve performance, process interactions, control strategy design and process capability, are often overlooked. These could be the problems preventing the loop from reaching the desired level of performance.

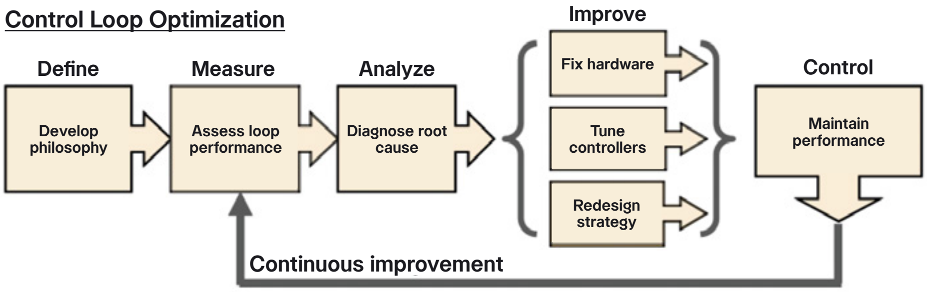


Figure 3. Loop improvement work process

The application of straightforward engineering principles, combined with new technology (Figure 3), can accomplish loop performance improvement in an efficient way that minimizes cost and resource requirements.

This is the kind of work that requires experts in control design – a scarce commodity. However, technology can help dramatically. Software incorporating the knowledge of current experts is available and easy to use. To get started, consider questions such as:

1. How many and which of my loops are being run in manual mode?
2. What are my top 20 worst-performing loops?
3. Which of my control valves experience either hysteresis or stiction?
4. Which control loops need better tuning coefficients and what should the values be?

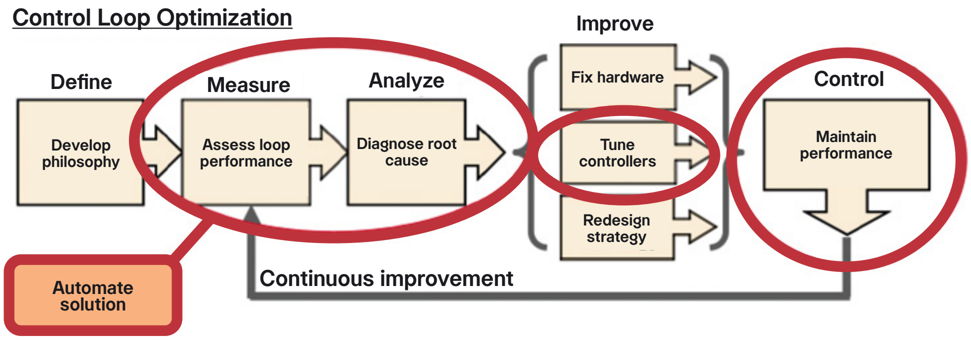
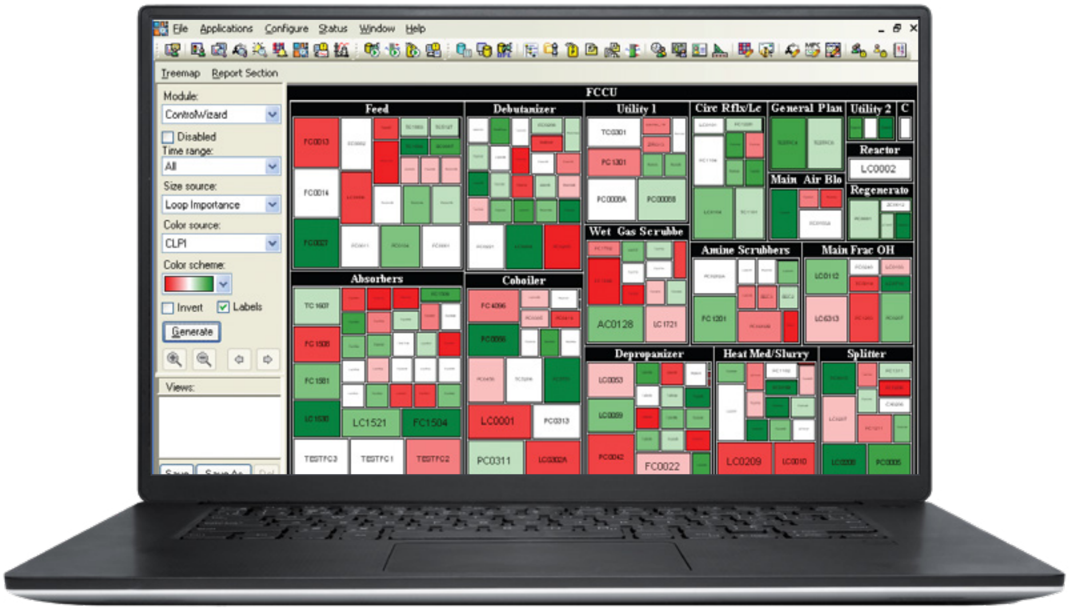


Figure 4. Loop improvement work process with possible automation

Software, such as Octave Tempo Control System Effectiveness (formerly PAS PlantState Integrity) - Tempo Control Loop Performance (formerly PAS ControlWizard), can continuously monitor a control system, identify problematic loops and perform dozens of analyses on them automatically. The answers are not just available "a click away" – they are generated and reported automatically. The power of this advanced software resembles a team of control experts continuously working on your system.



Module: ControlWizard

☐ Disabled

Time range: All

Size source: Loop Importance

Color source: CLPI

☐ Invert ☑ Labels

Figure 5. Tempo Control Loop Performance visualization of control loop performance for targeting improvement areas

Seven steps for optimizing control loop performance

The basic work process associated with optimizing loop performance can be condensed into seven straightforward and proven steps. Given current software capabilities, the steps involved in the solution are quite practical and attainable. They are:

1. Develop and adopt a process control philosophy
2. Assess current loop performance
3. Diagnose root causes of poor performance
4. Fix poorly performing hardware
5. Optimize controller performance
6. Implement advanced control strategies
7. Maintain performance over the long term

Step 1: Develop and adopt a process control philosophy

Loops are specified and configured during design. As controller points are "built" in a DCS configuration, the initial loop tuning coefficients are populated. These coefficients may be specifically entered based on experience with a similar loop or they may be just the default values provided by the DCS manufacturer. In the latter case, those default values are hardly ever optimal for a specific loop.

A process control philosophy is necessary to establish objectives and guidelines for all aspects of control loop optimization and to ensure an effort will be effective and consistently applied. Since multiple site roles are involved in loop improvement, the document is developed as a collaborative effort between control engineers and the operations and maintenance groups.

At a high level, the document should cover the following items:

- Define personnel and functional group roles and responsibilities, as well as the skills and training required
- Define the work process for control loop improvement, generally a team-based approach for immediate step-change improvement, plus a structured work process for maintaining those gains
- Document the guidelines for determining loop importance and for setting control loop performance criteria
- Define the documentation needed for each type of improvement
- Define standards for selecting different controller configurations, options and tuning rules based on loop types and performance objectives
- Define the implementation strategy and spell out a project plan
- Define reporting requirements and key performance indicators (KPIs) for tracking progress
- Define the operator training methods needed to support control changes, including any changes needed in the HMI
- Develop maintenance guidelines for sustaining improvement gains
- Maintain performance over the long term

Step 2: Assess current loop performance

Software can automate much of this step, both for an initial assessment and for ongoing monitoring for the life of the plant. Some software tools, such as Tempo Control Loop Performance, can automatically perform nearly all needed configurations by reading the DCS database. Other software may require a significant amount of human configuration effort.

Software can identify the worst-performing loops. Although the software should assess all control loops, human guidance should determine the order in which loops are improved, generally starting with the most important control loops showing the worst performance. Control loops should be classified according to their relative importance, and performance criteria should be assigned to the loops of high importance. As part of improving any individual loop, managers should try to calculate the value of each improvement.

Loop analysis requires the collection of controller output, setpoint and process measurement data from the DCS. OPC DA is a common method. Data should be sampled quickly enough to capture loop dynamics. A rate between 1/25th and 1/50th of the loop settling time normally provides good results. It is not recommended to collect data from process historians because that data is seldom sampled quickly enough to analyze the performance of fast control loops, and the data is often compressed, which negatively affects the accuracy of the performance analyses.

Various statistical and time-series analyses are used to further assess the control loops' performance and to diagnose problems. Industry literature widely describes these techniques. Tempo Control Loop Performance contains the following and more:

Some of Tempo Control Loop Performance automated analyses

Loop service
- Percentage of time in normal mode
- Operator changes
- Controller saturation

Control valve
- Travel/day
- Reversals/day
- Stiction
- Hysteresis
- Nonlinearity

Power spectrum analysis
- Dominant frequencies
- Significance of oscillation

Correlation analysis
- Autocorrelation of process variable
- Cross correlation of error and output

Cycle analysis
- Zero-crossing cycle detection
- Cross-correlation cycle analysis
- Cycle frequency analysis

Time series analysis
- ARMA model
- Impulse response
- Settling time
- Overshoot

Loop performance
- Harris index
- Control Loop Performance index

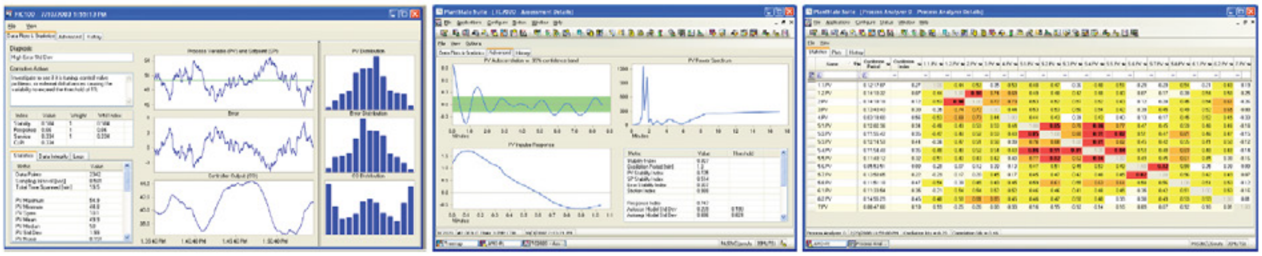


Figure 6. Tempo Control Loop Performance analyses

Step 3: Diagnose the root cause of poor control performance

It is important to establish whether poor performance is because of controller tuning, hardware or other factors, so that the appropriate corrective action can be taken. Engineers should inspect the identified list of poorly performing control loops to determine the root cause or causes. The assessment software provides potential diagnoses automatically from process data already captured. Single-loop diagnostic and tuning software can also assist by analyzing data from specific diagnostic tests that have been performed on the process.

Typical diagnoses may include hardware problems with final control elements (stiction, hysteresis, nonlinearity) and instrumentation (static sensors, spikes, noise) or tuning problems (aggressive or sluggish tuning).

Step 4: Fix poorly performing hardware

Some loop problems will be fixable solely via changes in the DCS configuration. If the control loop problem is related to defective hardware, the maintenance function must be involved. In some cases, the needed changes may involve waiting until a process shutdown occurs.

Different stroking:

Note that stroking a control valve in **25%** increments (a basic performance check done by many instrumentation technicians) does not reflect how well the valve will perform in normal operation when the movements required are often called for in fractions of one percent.

Although some controller tuning “tricks” might compensate for control valve hysteresis or stiction, the loop performance ultimately will not be as good as with a properly functioning control valve. In many cases, controller tuning with bad hardware is a futile exercise. Because of existing hardware problems, process characteristics can be misidentified, leading to improper and even dangerous controller settings.

Step 5: Optimize controller performance

If the hardware is reliable, the controller can be tuned to obtain the desired speed of response appropriate for the loop’s role in the process.

Controller tuning matches the static and dynamic characteristics of the controller (gain, integral and derivative) to those of the process (gain, dead time and lag). Before a controller can be tuned, it is necessary to establish the dynamic characteristics of the process. Software, such as Tempo Control Loop Performance, makes the identification of process characteristics and the calculation of the controller settings simple and error-free. It also provides simulations of predicted loop response and robustness. Using a software application to optimize controller performance significantly improves accuracy and saves time.

Step 6: Implement advanced control strategies

Even after the hardware is fixed and the control loops are properly tuned, the performance of some control loops may still need to meet desired specifications. Feedback control loops have inherent performance limits that cannot be exceeded, regardless of how well they are tuned. Processes could be interactive, nonlinear or inherently slow, which also limits what a single controller can do.

In cases like these, engineers can improve control performance by implementing a more complex control strategy. These advanced control strategies include cascade, feed forward and ratio control, gain scheduling, decoupling and model predictive control.

Hysteresis and stiction – the most common control valve problems -- explained

Tempo Control Loop Performance assesses and identifies the common pneumatic control valve problems of hysteresis and stiction, which may result from linkage problems or excessive stem friction. These physical valve problems manifest themselves as a lack of, or delayed, control response when a process controller requests the valve to make a change in control direction.

Hysteresis and stiction affect process control by behaving like a variable dead time, preventing changes in control output from producing any resulting change in the process variable. The magnitude of the controller output change has a direct bearing on the amount, if any, of delayed control response introduced. Larger controller output changes often possess the ability to overcome the stiction immediately, resulting in the desired corrective response in the process variable with minimal dead time. Smaller changes may have little or no immediate effect, and the PV – SP1 error must accumulate to a point sufficient that its corresponding output change is enough to move the stuck valve. This phenomenon introduces a delay in the control response (dead time). Faster responding controllers generally have shorter hysteresis-caused dead times. Slower responding ones have longer dead times. For this reason, and also because the magnitude of the SP - PV error changes, the dead time introduced by hysteresis and sticture is variable. This variability in the dead time virtually assures that SP - PV error will never be eliminated, resulting in controllers continually over- and under-shooting the target PV value. This is the very definition of control loop instability.

Controller tuning may soften the effect of hysteresis and sticture; but, cannot completely eliminate it. The only solution is to repair the control valve.

1. The PV, or process variable, is the measurement being controlled. The SP, or setpoint, is the desired value of that process variable. The difference between the two variables (SP - PV) is called error and it is the value that the PID control algorithm uses to calculate the change in control output (to move the control valve the desired amount). When the SP - PV = 0, then the control valve remains in its current position.

Step 7: Maintain performance over the long term

To sustain the benefits of optimization, it is essential to continuously monitor and report loop performance for the life of the plant. A best practice followed by many industry leaders is to compile control loop performance metrics and provide weekly/monthly reports to various stakeholders, such as automation and operations management team members.

The same software used for initially analyzing the control loop performance in step 2 normally can be used for this function. The team should analyze control loop performance periodically, at intervals from a few days to a week.

Three examples of successful control performance improvement efforts

Example 1: Refinery operation

An 84,000-barrel-per-day oil production facility was experiencing control loop instability. The controllers were originally tuned for low production rates and loops went unstable when production was increased. As a result, several process trips occurred because of separator level control.

- Each trip cost ~16 hours of lost production.
- Several loops could not be put into automatic control mode during startup.
- Each trip resulted in $4,500,000 of lost production.
- Startups took longer than necessary and were less predictable as operators were required to manipulate controllers in manual mode.

All these problems were solved by implementing a software-driven control loop performance effort.

Example 2: Distillation column

A chemical plant distillation column was experiencing cycling of liquid level because of interactions between loops. After software-driven analysis, the problem was addressed in two ways:

- Digital valve controllers were installed which minimized excessive control valve deadband.
- Loop interaction was addressed by manipulating the closed loop time constants to account for the process dynamics and interactions. The cycling of the liquid level was eliminated.

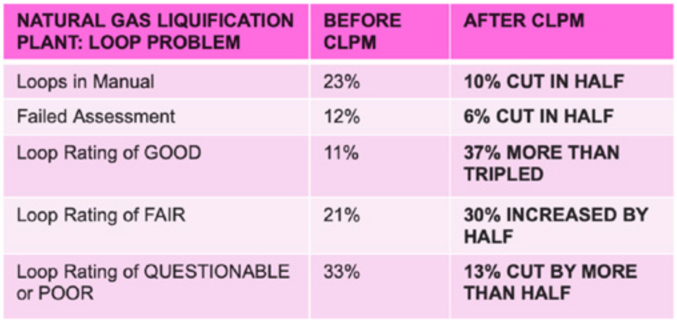
This loop optimization effort resulted in a 25% reduction in reflux and 5% energy saving from lower steam usage.

Example 3: Natural gas liquification plant

An operating plant contained more than 1,800 control loops. The plant experienced significantly inefficient operation and process upsets. Software analysis revealed:

- Poor control loop designs
- A high number of loops running in manual out of necessity

Loop Improvement resulted in significantly improved process efficiency and large monetary savings.



NATURAL GAS LIQUIFICATION PLANT: LOOP PROBLEM	BEFORE CLPM	AFTER CLPM
Loops in Manual	23%	10% CUT IN HALF
Failed Assessment	12%	6% CUT IN HALF
Loop Rating of GOOD	11%	37% MORE THAN TRIPLED
Loop Rating of FAIR	21%	30% INCREASED BY HALF
Loop Rating of QUESTIONABLE or POOR	33%	13% CUT BY MORE THAN HALF

Figure 7. Control loop performance management (CLPM) in a natural gas liquification plant

Summary

As the first line of defense against process disturbances, control loops play a significant role in plant safety, reliability and profitability. Avoidable risk in all these areas increases when loops do not perform properly. Yet, poor loop performance is widespread throughout the industry.

Substantial hard-dollar benefits are directly associated with improving control loop performance. Plants can achieve these improvements and largely automate them with a systematic and consistent approach. They can optimize control loops effectively and improve safety and performance by implementing a proven seven-step action plan.

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Bill is a retired principal consultant responsible for the areas of both alarm management and high performance HMI. He is a member of the ISA SP-18 Alarm Management committee, the ISA-SP101 HMI committee, The American Petroleum Institute's API RP-1167 Alarm Management Recommended Practice committee and the Engineering Equipment and Materials Users Association (EEMUA) Industry Review Group.

Bill has multi-company, international experience in all aspects of alarm management and HMI development. He has 28 years of experience in the petrochemical industry in engineering and operations, and an additional 18 years in alarm management and HMI software and services for the petrochemical, power generation, pipeline, pharmaceutical and mining industries.

Bill is co-author of *The Alarm Management Handbook, The High Performance HMI Handbook and The Electric Power Research Institute (EPRI) Guidelines on Alarm Management for both Power Generation and Power Transmission.*

Bill has authored several papers on alarm management and HMI and is a regular presenter on such topics in such venues as API, ISA, and Electric Power symposiums. He has a BSME from Louisiana Tech University and an MBA from the University of Houston.

In 2014, Bill was made an ISA Fellow.

About Octave

Octave is a leader in enterprise software, turning data into decisive action and intelligence into your edge. Our software solves for and simplifies complexity, from the design and build to operations and protection of people, property, and assets– for any scope, at any scale. For decades, we've partnered with customers to sharpen performance, elevate efficiency, and amplify results. From factory floors to entire cities, our solutions are tuned to scale up what's possible from day one onward.

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