Penrose Technologies, LLC

Integrated Advanced Process Control (IAPC)

Technology Share Program

Thomas J. Senyard, PE
Penrose CTO

The Art & Science of "Advanced Process Control": – Self-Regulating vs Non-Self-Regulating Loops

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For those APC Engineers who design, commission, and/or support APC Loops and Controls, a basic understanding of the two types/characteristics of Loops will assist with these efforts. As an example, if a particular control loops requires three cascaded PID controllers (Controller 1 → Controller 2 → Controller 3), EACH loop as a primary loop, inclusive of its secondary loop(s), should be evaluated as being a Self-Regulating (SR) or a Non-Self-Regulating (NSR) Loop.

Guided by the insight and knowledge described in this document, the APC Engineer should investigate any method/ means of converting any NSR Loops to a SR Loop or even a pseudo-SR Loop to aid in commissioning, tuning, and long term loop stability and robust performance.

Self-Regulating vs Non-Self-Regulating Loops:

There are two categories of controls that must be determined, recognized, understood, and not confused with each other. All control loops have to be evaluated as **Self-Regulating (SR)** or **Non-Self-Regulating (NSR)**; very few are in between. SR control should be viewed and configured similar to a flow controller – a change in output (valve) results in a "finite" change in input (most flows, some temperatures, some pressures, very few levels). If the loop is NSR, then a different approach for control is strongly recommended. This means that a change in output (valve) results in a theoretically "infinite" change in input (some temperatures, some pressures, most levels).

Definition of SR Loops:

Flow – Any loop in which a change in manipulated variable or control element results in a finite flow change, whether linear or non-linear. An example would be flow of liquid (flow or vaporization), gas (flow or condensation), heat (heating medium or electrical), solids, and electrical (amps).

Temperature – Any loop in which a change in manipulated variable or control element results in a finite temperature change, whether linear or non-linear. An example would be a "heated" flow/stream, as opposed to heating of a "volume" or "mass".

Pressure – Any loop in which a change in manipulated variable or control element results in a finite pressure change, whether linear or non-linear. An example would be a pressure control valve, as opposed to changing the pressure in a vessel.

Level – Any loop in which a change in manipulated variable or control element results in a finite level change, whether linear or non-linear. Examples of SR level loops are rare.

Definition of NSR Loops:

Flow – Any loop in which change in manipulated variable or control element results in a potentially or relatively infinite flow change, requiring the loop to increase then decrease the manipulated variable/element (or visa-versa) for control. Examples of NSR flow loops are rare; do not confuse this with catalyst injection flows, pH control, etc., since the flow itself would be SR, but the primary loop ABOVE the flow loop (which contains/ incorporates the flow loop) would be NSR.

Temperature – Any loop in which change in manipulated variable or control element results in a potentially or relatively infinite temperature change, requiring the loop to increase then decrease the manipulated variable/element (or visa-versa) for control. Do not confuse this with the actual heat/cooling flow loop itself (since the flow of vapor/ liquid/ amps/ steam/ heat/ cooling itself would be SR), but the primary temperature control loop ABOVE the flow loop (which contains/ incorporates the flow loop) would be NSR. An example would be a "heated" vessel, reactor, anything containing the heating/ cooling of a "volume" or "mass".

Pressure – Any loop in which change in manipulated variable or control element results in a potentially or relatively infinite pressure change, requiring the loop to increase then decrease the manipulated variable/element (or visa-versa) for control. Do not confuse this with the actual flow loop creating pressure itself (since the flow of vapor/ liquid/ amps/ steam/ heat/ cooling itself would be SR), but the primary pressure control loop ABOVE the flow loop (which contains/ incorporates the flow loop) would be NSR. An example would be a pressure control of a vessel, reactor, anything containing a "volume". Another example would be a vacuum pump or compressor to alter pressure.

Level – Any loop in which change in manipulated variable or control element results in a potentially or relatively infinite level change, requiring the loop to increase then decrease the manipulated variable/ element (or visa-versa) for control. Do not confuse this with the actual flow loop itself (since the flow of vapor/ liquid/ amps/ steam/ heat/ cooling itself would be SR), but the primary level control loop ABOVE the flow loop (which contains/ incorporates the flow loop) would be NSR. An example would be a level control of a vessel, reactor, anything containing a "volume".

Problems Encountered with NSR Loops:

Overview - NSR controls must not be treated as SR controls. Treating NSR controls as SR controls creates false dynamics, which are difficult to compensate for effectively. NSR control is more correctly viewed and treated as a "capacity control", while SR control is a "rate control". Other parameters must be incorporated and established to properly control the actual process parameter that does not create false dynamics. Most problematic controls in an industrial plant are NSR.

Auto-Tuning Algorithms – Auto-Tuning Algorithms work quite well with SR Loops, unless they have extensive dead-times (typically a dead-time greater than 3-4 times the process time constant become difficult to tune by any means, dead-time greater than 2 times the process time constant doesn't auto-tune well.

Auto-Tuning Algorithms do NOT work well with NSR Loops … Again, SR Loops are rate ($time^{-1}$) or volumetric ($volume^{-1}$) controls , but NSR are capacitance controls. Means exist to convert NSR Loops to act predominantly like a SR Loop, and the designer of APC needs to incorporate such a solution into their strategies.

MPC Control – One of the two weakest links (rather, more of an "Achilles' Heel") in the use of Model Predictive Control (MPC) of Industrial Processes is their inability to model NSR Loops. The concept of using MPC techniques to derive curves for what is essentially a Linear Program to solve cause/effect in a process doesn't work well with the concept of variable capacitance (NSR Loops) … variable rate (SR Loops) modeling works well.

Where does the diligent APC Engineer go from here?

Over time Penrose will provide more insightful papers to expand the understanding of the importance of discerning between SR and NSR Loops. As a multi-layer / multi-tiered control strategy is developed, you must evaluate each loop and any secondary loops contained within and determine if it is SR or NSR. Obviously the easiest to do then is develop a means of creating a SR Loop or "pseudo" SR Loop out of a NSR Loop so it will tune well and become a robust APC Loop, whether implemented in a Distributed Control System (DCS) or in a Model Predictive Controller (MPC).

Thomas J. Senyard, PE, is Chief Technology Officer (CTO) of Penrose Technologies, LLC, a provider of game changing results by the use of Integrated Advanced Process Control (IAPC) primarily in the refining, petrochemical, chemical, and polymer industries.

After his early beginnings at Exxon Chemicals, Thomas formed (with his father, Corley P. Senyard, Chief Advanced Control Engineer Technologist for Exxon Chemicals North America) and was President/CEO of Quad-S Consultants, Inc. beginning in 1981.

Quad-S Consultants made the Inc. 500 List twice in the 1980s, working throughout various refining, petrochemical, chemical, and polymer industries. After conducting parallel projects within Union Carbide against respected companies such as Setpoint Controls, Simcon, Profimatics, and Honeywell's Icotron, Quad-S went on to sign a 5 year agreement in 1995 with Union Carbide Chemicals and Plastics, reporting directly to the Directors and Vice Presidents to exclusively provide "Manufacturing Optimization and APC" throughout Union Carbide.

Although Dow Chemicals acquired Union Carbide in 2001 and chose not to extend the terminated agreement, Thomas has continued to develop, provide and implement future enhanced generations of IAPC, continuing to strive for "near-hands off" control designs for a multitude of processes.

Thomas is now a founder and CTO of Penrose Technologies, a technology company focused on "blueprinting" the various proven process IAPC strategies into a more modular, easier to implement and support format.