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Upstream Tank Battery Pressure Management using PLC-based MPC

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Abstract

A PLC-based multivariable controller is being used to manage central tank battery pressures and minimize well-head backpressure, while honoring gravity-feed flow requirements and process constraints. The controller adapts to varying well line-ups and rate changes as well as downstream pressure swings, significant valve stiction and significant ambient-temperature swings. The controller was designed and implemented using Lin and Associates' Model-less Multivariable Controller, DELTUM®. The first DELTUM controller was commissioned in less than three days with no need for step-testing or process modeling; operating benefits were immediately recognized. A second controller with the same design was installed on another tank battery with different operating constraints and commissioned before the end of the first week. The project team installed controllers on additional tank batteries.

1 Problem

The Chevron Mid-Continent Business Unit operates central tank batteries (CTBs) in the Permian Basin. Well fluids, a mixture of oil, gas and water, flow from the wellheads to a series of typically three (3) three-phase separators. As the fluids progress through the system, gas and water are removed in each separator in the series with the oil going to a storage-tank. The separators, tank and low-pressure compression comprise the tank battery. Gas off the separators is routed to the pipeline; process water is sent to a storage tank.

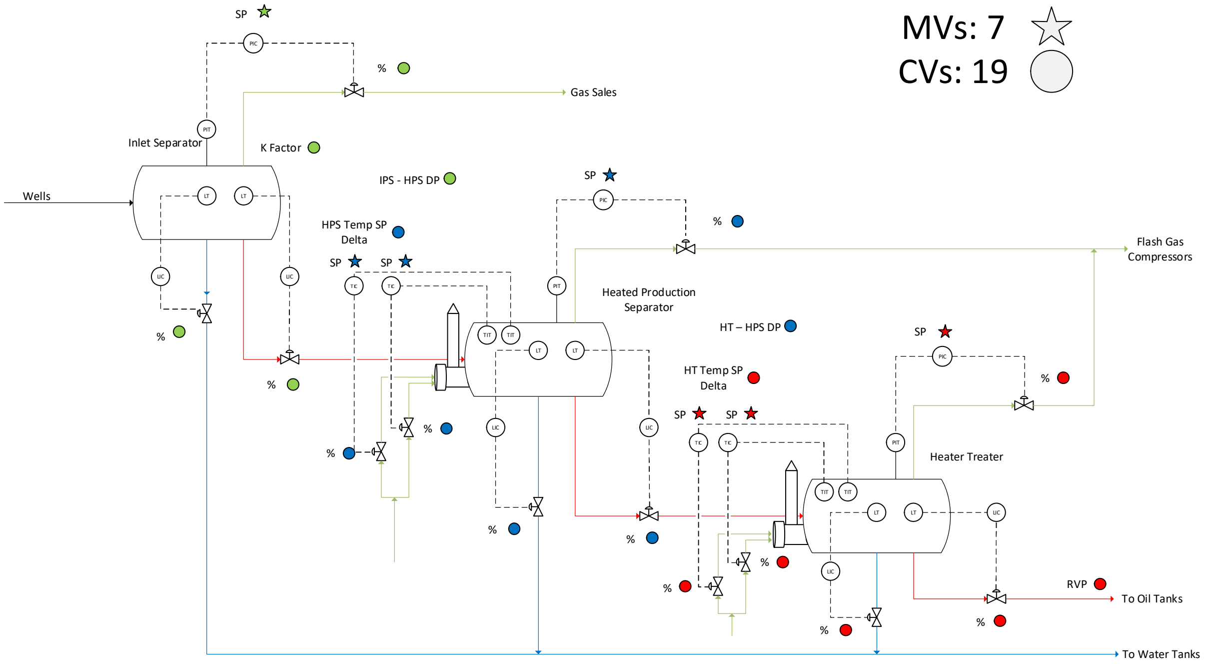

Figure 1: Central Tank Battery Process Flow Diagram

2 Central Tank Battery Operating Objectives

The main operating objective of the CTB is to maintain forward flow of oil, gas, and water. In most configurations, there are no pumps so forward flow must be maintained by using/managing differential pressures between vessels. Additional objectives include:

1. Stabilizing events during normal operation which include adding and removing producing wells and substantial changes in ambient conditions and minimizing the need for remote or local operator intervention.
2. Controlling oil Reid Vapor Pressure (RVP) in the oil storage tank below shipping limit.
3. Minimize oil-condensate loss in the gas system.
4. Minimize wellhead back-pressure.

While oil and gas reserves are fixed, the well's production rate at a given time is a strong function of back-pressure on the well. Adjusting the main separator inlet pressure subject to other CTB constraints provides some level of production and reservoir management to the engineering and production team.

3 Control System

The control system at the CTB is hosted on a programmable logic controller (PLC). The PLC used for this application is an Emerson/GE CPL410[1]. The CLP410 is a dual-processor PLC. Traditional PLC ladder logic is running on one processor and using the same operating system as other Emerson/GE PLCs. The other processor is running the Linux[2] operating system. DELTUM is running on the Linux processor and communicating process data and control moves to the PLC-side via Modbus. CTBs spread over the Permian Basin are operated from a central control facility in Midland, TX. Engineers and console operators in the central control room interact with the DELTUM controllers using a web interface hosted in the central control facility. DELTUM can be turned ON and OFF by central control room console operators; DELTUM can be turned OFF in the field using the PLC panel or a physical field switch. There are watchdog fail-safes in-place to force DELTUM OFF if communication is lost between DELTUM and the PLC.

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[1] Emerson is a registered trademark or Emerson Electric Co. GE is a registered trademark of Generical Electric

[2] Linux is a registered trademark of the LINUX Foundation

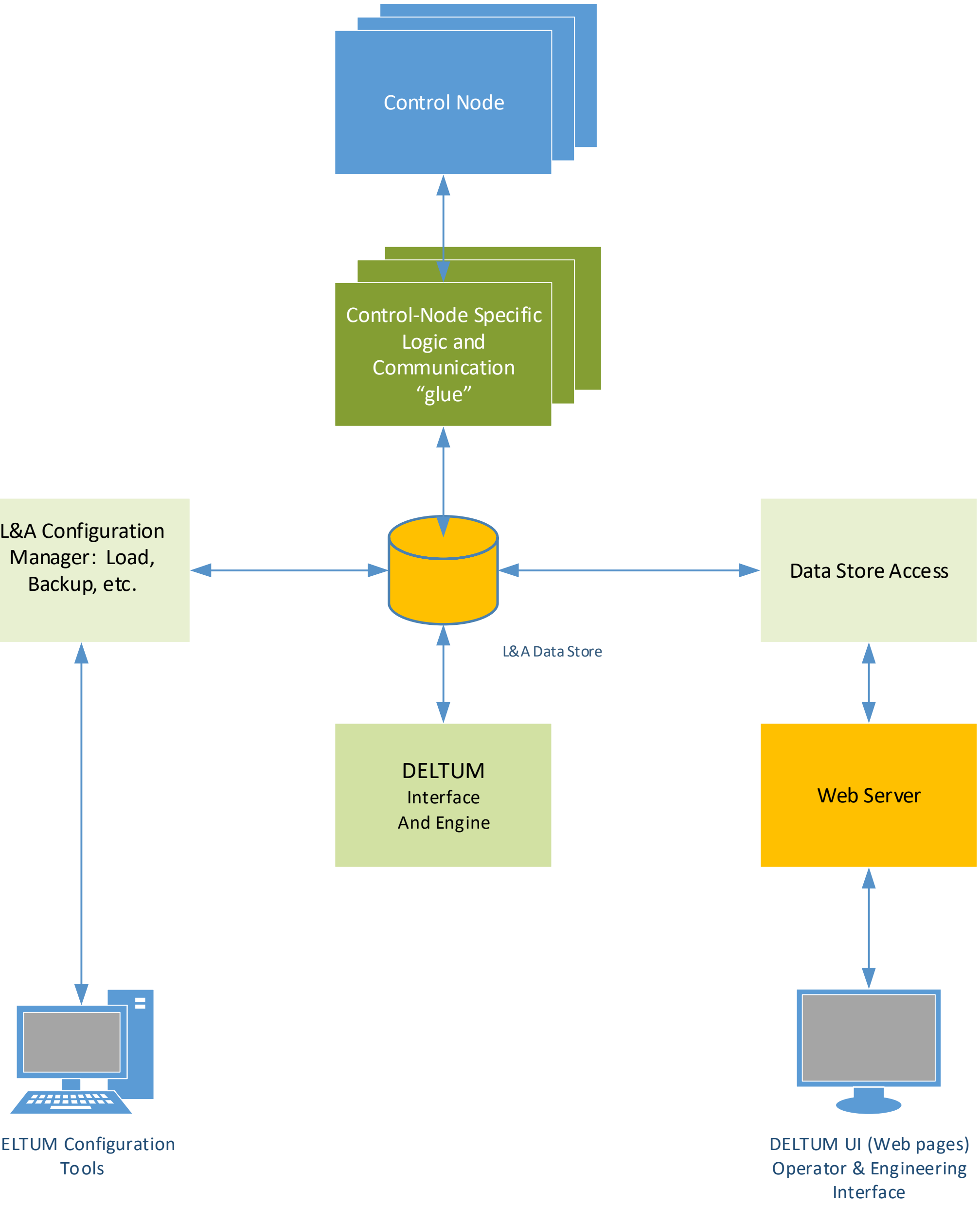

Figure 2: System Architecture

Multiple tools and computer languages were used to implement the solution as quickly as possible with emphasis on cyber-security, robustness, and ease-of-use. The list of components and tools includes PLC ladder logic, Modbus[3] communication protocols, applications from the Microsoft Visual Studio suite of languages, and SQL[4].

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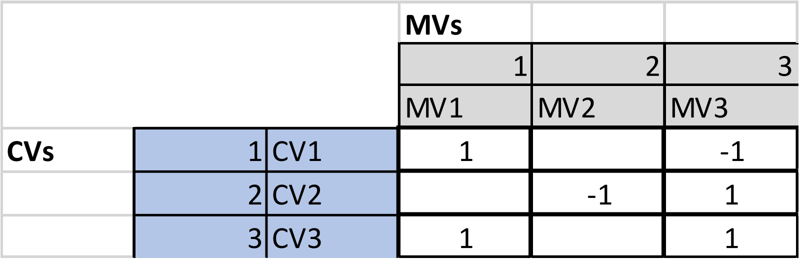
[3] Modbus is a registered trademark of Schneider Electric USA, Inc.
[4] Microsoft Visual Studio is a registered trademark of Microsoft Corporation.

The solution was built and tested in phases that included control and software tests on a pseudo first-principle based simulation, isolated software component testing, a full bench-test, cyber-security penetration testing, and finally a heavily monitored field test.

4 DELTUM Controller and Solution Development

The DELTUM controller is a multivariable model-less controller which solves the multivariable control problem using a patented solution algorithm. DELTUM moves one or more setpoints or outputs to control one or more values. The setpoints/outputs moved by the controller are called manipulated variables (MVs); the variables that are monitored/controlled are called controlled variables (CVs). The DELTUM control algorithm is based on a controller response matrix which calls out the directional relationships between MVs and CVs. Engineers, and in some cases, operators, define the relationship matrix. If a CV increases when the MV is increased, the response is positive or one (1), if the CV decreases when the MV is increased, the response is negative or minus-one (-1), and if there is no change in the CV when the MV is moved, then there is no response or a zero (0).



			MVs		
			1	2	3
			MV1	MV2	MV3
CVs	1	CV1	1		-1
	2	CV2		-1	1
	3	CV3	1		1

Figure 3: Example of ACTUAL Matrix Relationships

To accelerate the control testing and PLC-based software development efforts and to create a bit of a "blind" between the process simulation details and the controller design and tuning, the team was divided into two groups:

1. Simulation team: Built a representative pseudo-first-principle dynamic model of a two-separator CTB. The initial calculations were developed and validated using Excel[5] and the simulation was implemented in a DCS in function-blocks.
2. Controller design team: During a few-hour meeting, the controller design team created the controller response matrix and set controller tuning parameters such as maximum and typical MV moves.

As part of the initial control/software testing feed rate and conditions, downstream pressures and regulatory controller tuning constants were changed to simulate normal operation, typical

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[5] Excel is a registered trademark of Microsoft Corporation.

"event" scenarios and control-valve stiction/performance problems. DELTUM's control response adapted to match the different process conditions and changing system dynamics.

DELTUM includes the ability to minimize, maximize, or drive an MV or CV to a target-valve. Target values can be entered by the Operator or provided by an external program or another DELTUM controller. These options were exercised as part of the simulator testing to minimize separator pressures subject to operating and equipment constraints and to control the oil Reid-vapor-pressure (RVP) to a target value.

5 Controller Solution and Benefits

In the field, after loop-checks and an initial test-run, the first CTB DELTUM controller was turned ON by Operations. Initial results and Operator acceptance on Day-1 was so positive that the DELTUM controller was cloned to the second train at the CTB the NEXT day. To date, DELTUM has been commissioned on two (2) additional CTBs encompassing three (3) additional trains; the rate-limiting-factor to rolling out DELTUM on additional CTBs is regulatory control and instrumentation requirements on the CTB separators. Before going to the field, the control matrix was adjusted slightly to account for changes in some of the CVs from process values to valve-positions, but the live controller essentially used the same response matrix that was developed for the simulation testing. DELTUM controller commissioning also began with the tuning constants from the simulation test; only a few tuning parameters required adjusting when commissioning the first CTB. While CTBs have different capacities, the process is common; the only adjustments which needed to be made when "cloning" DELTUM to the next CTB was to adjust the control matrix to account for multiple water draws existing on some systems. While the console operators need to set appropriate operating limits for each CTB based on system size and particular operating conditions, the DELTUM controller tuning parameters did not need to be adjusted after initial tuning on the first CTB. Using the same tuning across all DELTUM CTB controllers simplifies adding the "next" CTB controller and potential maintenance of those controllers. With different CTB sizes and operating conditions, being able to use the same tuning parameters on all the controllers was a welcome surprise for the project team.

To add a new controller, engineers need to build the unique controller configuration that maps the MV and CV values in DELTUM to the specific PLC input/output registers and then test all the MV and CV communication links. Once the configuration is in place, the focused engineering commissioning time to add a new DELTUM controller to a CTB takes about one engineering day (plus time for operator training).

The DELTUM CTB allows production and reservoir engineers to manage production rates. During typical operation, DELTUM minimizes the inlet separator pressure to process constraints. Here is a trend of the first few hours of DELTUM operation:

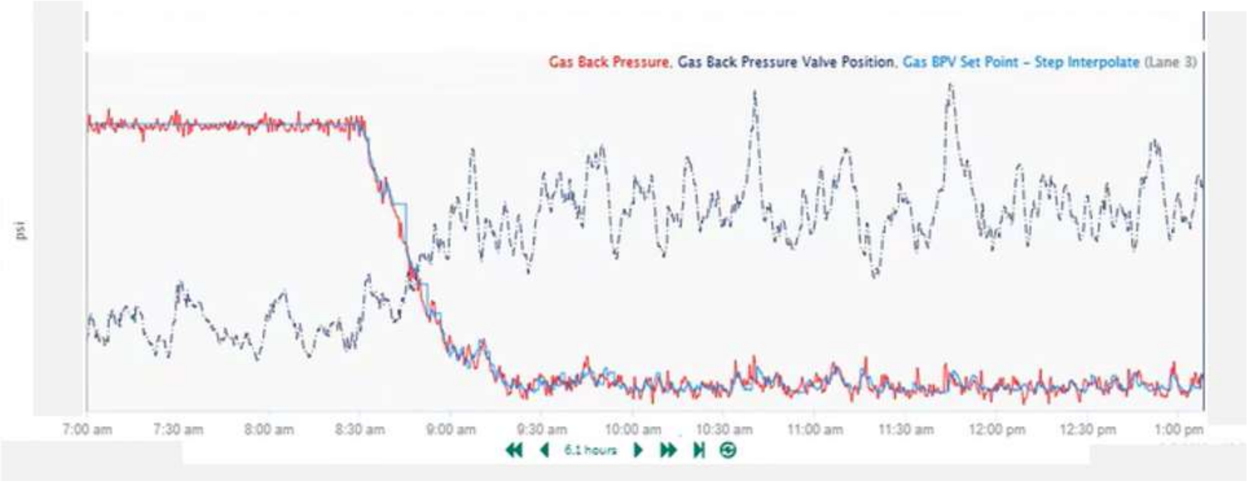

Figure 4: When was DELTUM Turned ON?
Thirty Percent (30%) Pressure Drop

Additionally, the CTB controllers are tolerant of:

1. Over 50% change in load/inlet rate,
2. High control valve stiction, proportional-integral-derivative (PID) tuning changes and control valve change-outs,
3. Significant changes in downstream pressure when one or more compressors at a compressor station are unavailable or trip, which creates an almost instantaneous 20+% change in backpressure on the separators, and
4. Noisy instrumentation.

The different CTBs present different process constraints and operating limits such as separator pressure, vessel-to-vessel dP, pressure and level control-valves and gas, oil, or water-limited operation to DELTUM. DELTUM is using the same control matrix and tuning for 5 trains representing 3 CTBs. In the eight months since initial controller commissioning, control matrix and tuning maintenance/adjustments have not been required.

At the site, there is a safety-interlock-system (SIS)-like well management program running in the background that can throttle or kill (trip) wells to prevent separator over-pressure or overfill scenarios. The system provides an automatic layer-of-protection to the entire field operation. The wellheads are remote/unattended and most require a site-visit to re-start. DELTUM manages CTB operation to not challenge the safety-system, reducing the overall operator stress levels. This benefit has helped drive operator acceptance so that DELTUM controllers have a service factor approaching 100% barring instrumentation/transmitter faults.

6 Closing Stories

We will leave you with stories from commissioning and a post-maintenance CTB restart:

1. While commissioning, one of the compressors downstream of the CTB tripped; that compressor is operated from another control console. DELTUM managed the increasing backpressure on the separator by increasing and balancing separator pressures in the CTB such that there were no process alarms from the CTB, and the overall separator pressure increase was minimal. Since the compressor was operated from another control console, there were no compressor-trip alarms on the CTB console. By limiting increased backpressure on the wells, Operations was able to maintain targeted product rates. Several hours later, when full compression was restored, DELTUM re-optimized the system, decreasing separator pressures to minimum limits. During the upset, CTB Operator was busy coordinating well operation on another CTB, without a compressor or separator alarm, the operator had not noticed the slight pressure increase on the CTB until the engineering team went to the console to ask questions.

2. After initial commissioning, Operations was hesitant to add or "POP" wells into the DELTUM-controlled CTB. However, after DELTUM managed flow deviations through the initial well POP without operator intervention or intervention from the SIS-like safety system, Operations now wants DELTUM in place and available when changing the well line-up to a CTB or bringing a CTB back online after a planned outage. DETLUM dynamic response has proven to greatly reduced required operator time during field start-ups.