Embedded APC Tools Dramatically Lower Implementation Costs: A Refinery Case Study

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Abstract

Ergon West Virginia Inc. recently installed a new digital control system (DCS) on part of their Newell, WV lube oil refinery. This paper describes the application of embedded Advanced Process Control (APC) tools on the atmospheric crude and vacuum columns in the refinery. The project included the use of two Model Predictive Controllers (MPC) along with neural-net inferential sensor technology to stabilize control of the critical product properties in the columns. Utilizing embedded APC technologies allowed Ergon to implement the project for a fraction of a traditional APC project costs while still achieving significant reduction in variability and capturing most of the potential benefits from this technology.

Introduction

Ergon operates a 20,000 BPD lube oil refinery in Newell, WV which has recently completed the second phase of a control system modernization project for a number of process units. As part of the project, a modern DeltaV DCS from Emerson Process Management was installed and most of the associated field devices were upgraded to smart instruments using Foundation Fieldbus technology. Phase II conversion included the Crude Unit, Propane Deresining Unit, Vacuum Fractionation Unit, and Sour Water Unit. Several more phases of the control modernization project are planned over the next few years to complete the remaining refinery process units.

The total size of the Phase II project included a total of around 580 I/O, of which approximately two thirds were Foundation Fieldbus (FF) with one third conventional I/O. For those loops that are on FF, the actual control algorithm is executed in the device rather than the DeltaV controllers.

History has shown that today's modern digital control systems, with their ability to incorporate Advanced Process Control (APC) functions, can deliver substantial performance improvements over traditional control systems. With new APC tools that are embedded in the DCS platform, the incremental cost to deploy these strategies has dropped dramatically as compared to older DCS systems. Nevertheless, many control system replacement projects do little more than replicate the previous control logic. Consequently, much of the potential benefits are never realized or at least postponed for several years.

Ergon had a different approach for their control modernization project. As part of the project engineering, the control system vendor reviewed Ergon's regulatory control strategies and recommended enhancements that would improve the operation of the units and take advantage of some of the features available in the new DCS. In addition, the engineering team reviewed the process operating objectives as well as the incentives and economics and identified areas that would benefit from APC applications. This review was incorporated into the front-end engineering for the project and the enhanced regulatory controls and APC functions were planned from the outset.

This paper describes the use of the embedded APC tools to achieve incremental improvements in the operation of the Crude and Vacuum Distillation units at the refinery.

Process Description

The Atmospheric Crude / Vacuum Distillation Unit (CDU) at the Newell refinery represents a typical process configuration for a lube refinery. Crude is preheated in a number of product and pumparound exchangers before entering a flash tower that removes light components from the crude feed. The crude is further heated in a 2-pass heater that fires refinery fuel gas to control a combined coil outlet temperature. The atmospheric column produces a straight run naphtha (SRN) product overhead, and three side-draw products: kerosene, heavy kerosene and atmospheric gas oil (AGO), which go through strippers before going to storage tanks. Two pumparound systems remove heat from the tower and preheat crude. The overhead vapors are condensed in a set of fin-fan exchangers. A simplified process flow diagram of the Atmospheric Column is provided in Figure 1 below.

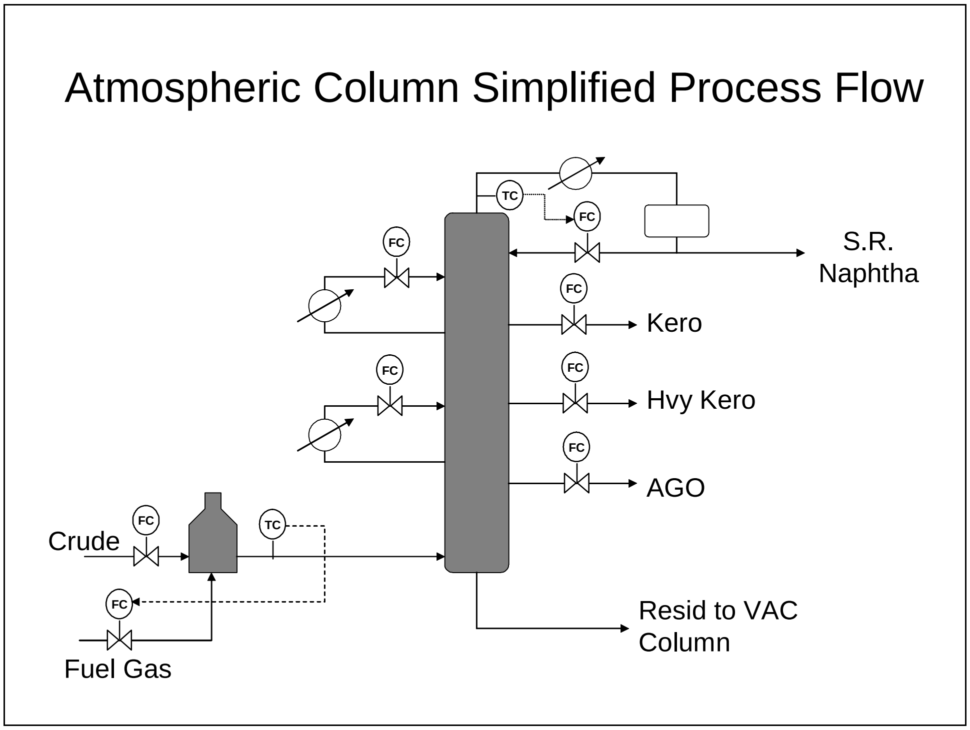

Figure 1

Atmospheric resid is taken from the bottoms of the atmospheric crude tower and fed directly to the Vacuum Tower heater. This is a 2-pass heater, also fired primarily with fuel gas. The vacuum column uses a steam ejector system that reduces pressure to nominally 50-70mm Hg. Three sidedraw products are removed from the column and sent to their respective strippers. The side draw products are Vacuum Gas Oil (VGO), wax distillate and heavy wax distillate. The top section of the column is packing with a total draw tray for the VGO product. Part of the VGO stream is cooled in fin-fan exchangers and returned to the top of the tower as cold reflux and part bypasses the exchangers and is returned as hot reflux. A portion of the heavy wax stream is also returned to the tower as hot reflux for the bottom section of the column. A simplified process flow diagram for the Vacuum Column is provided in Figure 2 below.

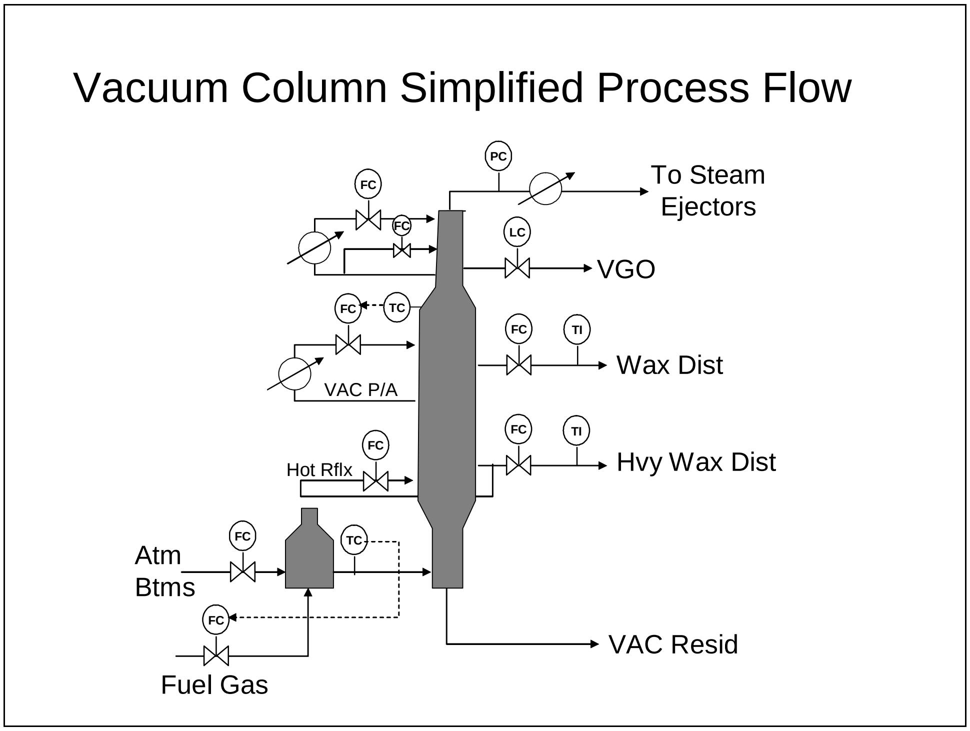

Figure 2

The Newell CDU typically runs a consistent slate of Appalachian crudes chosen to maximize production of the valuable lube stock components. Key product qualities are the endpoints of the various side draws that are sold directly as finished products, processed in downstream units or blended into final product grades. Lab samples of the key products are taken every 4 hours and the column yields are adjusted accordingly,

The CDU is rarely the refinery bottleneck, so limited incentives exist for increased capacity. The main process disturbances are caused by switching crude feed tanks and weather related upsets.

Advanced Control Strategies

The APC functions were designed to make use of the embedded tools within the DCS, primarily using Model Predictive Control (MPC) and Neural Net blocks. The control objectives for both columns are:

- Stabilize the column and control against desired product quality targets
- Maintain the unit within specified constraints and process limits
- Increase yields of the more valuable products up to their key quality specifications.
- Minimize upsets during crude switches and inclement weather.

These objectives are met with a combination of MPC blocks that manipulate the reflox flow and product draw flows to control the tower temperature profiles. Neural-net inferential sensor applications provide real-time indicators for the key product qualities. Pressure Compensated Temperature (PCT) calculations are used to account for the effect of pressure fluctuations on the tower temperatures and further stabilize the key product quality variables.

For the Atmospheric Column, the MPC block is configured with the following variables:

Variable	Description
MV1	Reflux Flow
MV2	Kero Draw
MV3	Heavy Kero Draw
MV4	AGO Draw
CV1	Tower Overhead Temp
CV2	Kero Draw Temp
CV3	Heavy Kero Draw Temp
CV4	AGO Draw Temp
DV1	Reflux Temperature
DV2	Heater Outlet Temperature
DV3	Total Charge Flow
CNST	None

Where:
MV = Manipulated Variable
CV = Controlled Variable
DV = Disturbance Variable
CNST = Constraint Variable

A Neural block is used to predict naphtha and AGO end points in real-time to provide operator guidance. Inputs for the neural block include the tower tray temperatures, pressures, product yields, heater outlet temperature, stripping steam and reflux rates. The inferential predictions may eventually replace their corresponding PCT as controlled variables as sufficient plant data is accumulated to obtain a robust and accurate prediction.

For the Vacuum Column, the MPC block controls three controlled variables, essentially the tray temperatures (PCT's) in the column that were found to respond best to changes in the product draw rates. The Vacuum Column controller includes the following variables:

Variable	Description
MV1	T-102 Pump Around Flow
MV2	Wax Distillate Flow
MV3	Heavy Wax Distillate Flow
CV1	VGO Chimney Vapor PC Temp
CV2	Wax Distillate PC Temp (Tray 11)
CV3	Heavy Wax PC Temp (Tray 7)
DV1	Pump Around Temperature

Variable	Description
DV2	Heater Outlet Temperature
DV3	Total Charge Flow
CNST1	Wax Distillate Draw Temp

A Neural block is used to calculate the wax distillate 95% point, primarily for operator guidance. Inputs for this block include the tower tray temperatures, pressures, product yields, heater outlet temperature, stripping steam and reflux rates.

A New Project Methodology

Due to the embedded nature of the APC tools, the application of advanced control is much easier and most activities happen at the plant on the actual operating system. The engineering required for implementing, staging and testing the solution has been greatly reduced. The project started with a 3-day kickoff meeting at the plant to confirm the APC objectives, design the control strategies and perform preliminary step tests on the units to capture basic process dynamics and constraints. A brief Functional Design Specification (FDS) document was prepared which defined the advanced control block configuration, special calculations and testing procedures. The advanced control functions were configured directly from this document, eliminating the need for a separate Detailed Design phase. Configuration of the complete advanced control applications for both columns, including the custom PCT calculations, MPC and Neural blocks as well as modifications to the operator graphics was completed in less than a day.

The configuration of the Atmospheric Column MPC block is shown in Figure 3 below. This configuration is done graphically using the Control Studio environment, in much the same way as a PID or other control block is configured in the system. The embedded APC tools automatically set up the history module as well as the regulatory control mode checks, watchdog timers, failure mode switching and other functions required for a closed-loop control system.

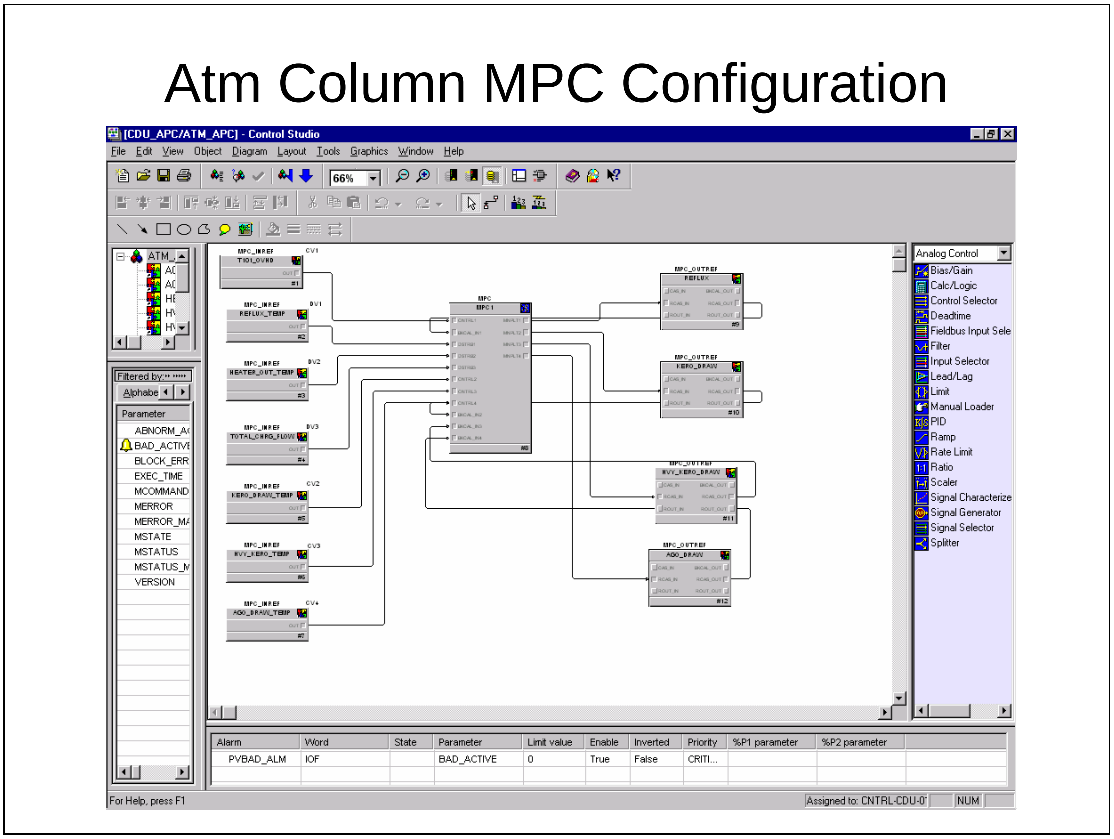

Figure 3

Once the configuration is complete, the modules are downloaded to a controller or an application station and the automated step test tools are used to step the manipulated variables. The MPC automated step test tool uses a "pseudo-random binary signal" (PRBS) approach to step tests which moves all variables around their current setpoint in a special test pattern. The MV's can be stepped individually or at the same time, depending on the complexity of the process and the experience of the user. An example step test setup and execution screens for the Atm Column AGO product is shown in Figure 4 below.

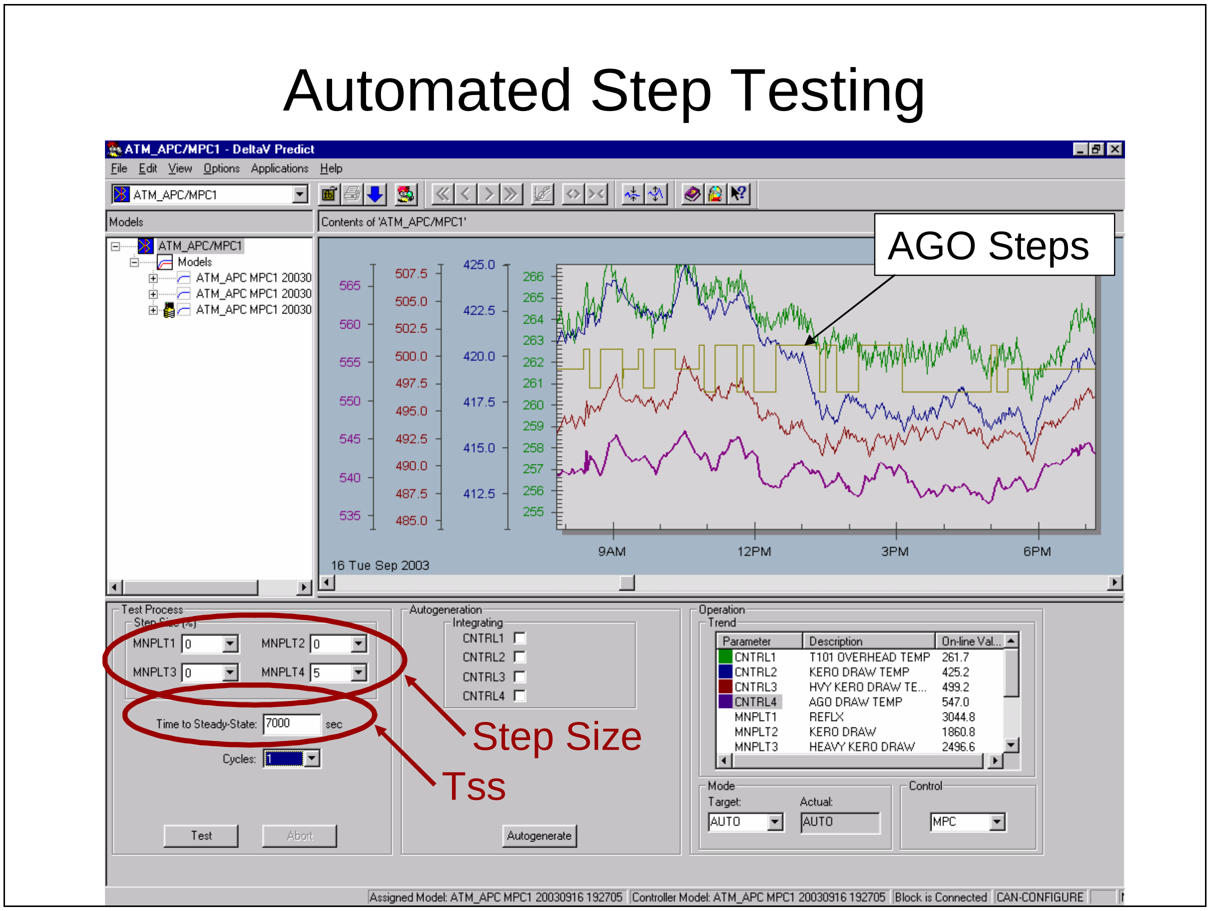

Figure 4

To initiate a step test, only the step size for each MV and the time-to-steady-state (Tss) needs to be entered. Pressing the "Test" button starts stepping the MV setpoints in an automated pattern around their current point. At any time, the operator can change the setpoints of any manipulated controller without affecting the test.

As the step tests are completed, the built-in model identification package is run against historical data to fit the models and validate their results. The final models obtained for the Atmospheric Column are shown in Figure 5 below. This figure shows the final step response curves observed for a 1% change in the MV or DV. From this view it is apparent that the top reflux flow (MV1), reflux temperature (DV1) and heater outlet temperature (DV2) had a strong impact on all four of the tower tray temperatures, thus leading to the interactive nature of the crude fractionation control problem.

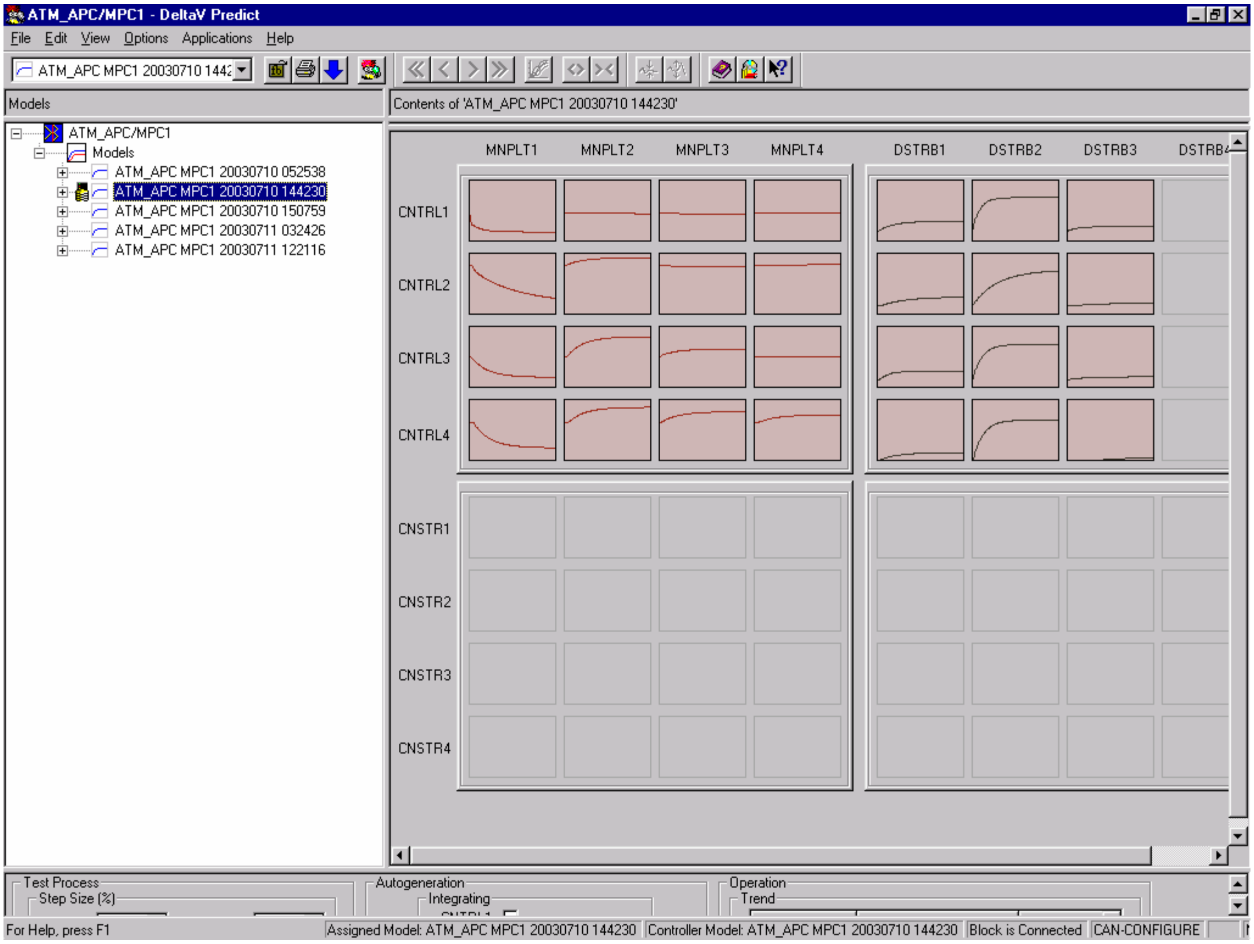

Figure 5
Atmospheric Crude Column Models

Models are validated against original or selected process data by clicking the "Validate" button and selecting a timeframe. The validation results from Ergon, showing actual vs. predicted are shown in Figure 6 for each of the 4 CV's. The observed offsets between some of the actual and predicted values that can be seen in these figures are not an issue as long as the process gain and time constants are reasonably correct. These offsets represent biases caused by "unmeasured disturbances" that can be corrected for on each execution of the controller. Basically, these step tests have yielded some fairly good models that explain most of the variation seen for each of the CV predictions over the step period.

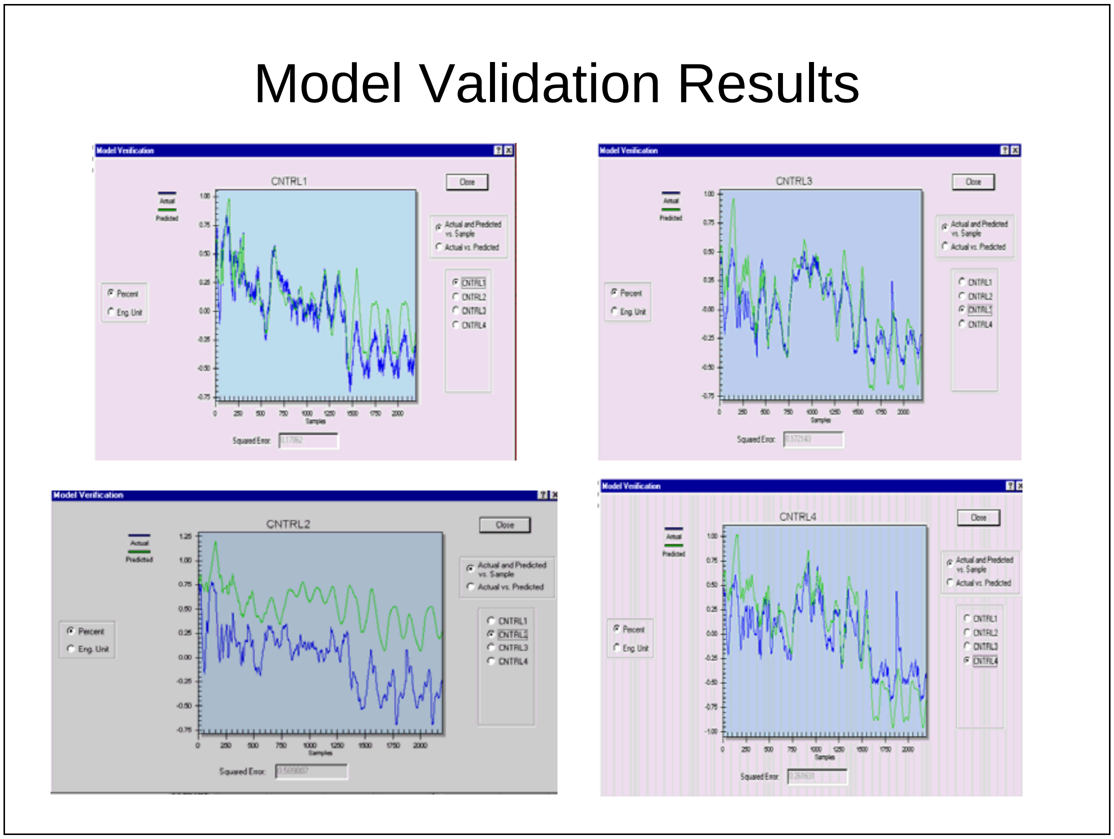

Figure 6

While waiting for the step tests to complete, all of the neural blocks were trained using process and laboratory data stored in the refinery data historian system. The built-in Neural Tools provide the ability to set a delay value for each input. This delay is calculated automatically to obtain the best correlation between the input and output variables, but ultimately needs adjustment based on process knowledge. For each predicted variable, a reasonable fit was obtained in the initial training set, so these calculations were put on-line and the lab update functions enabled. Figure 7 shows the Neural training results for the naphtha endpoint as an example.

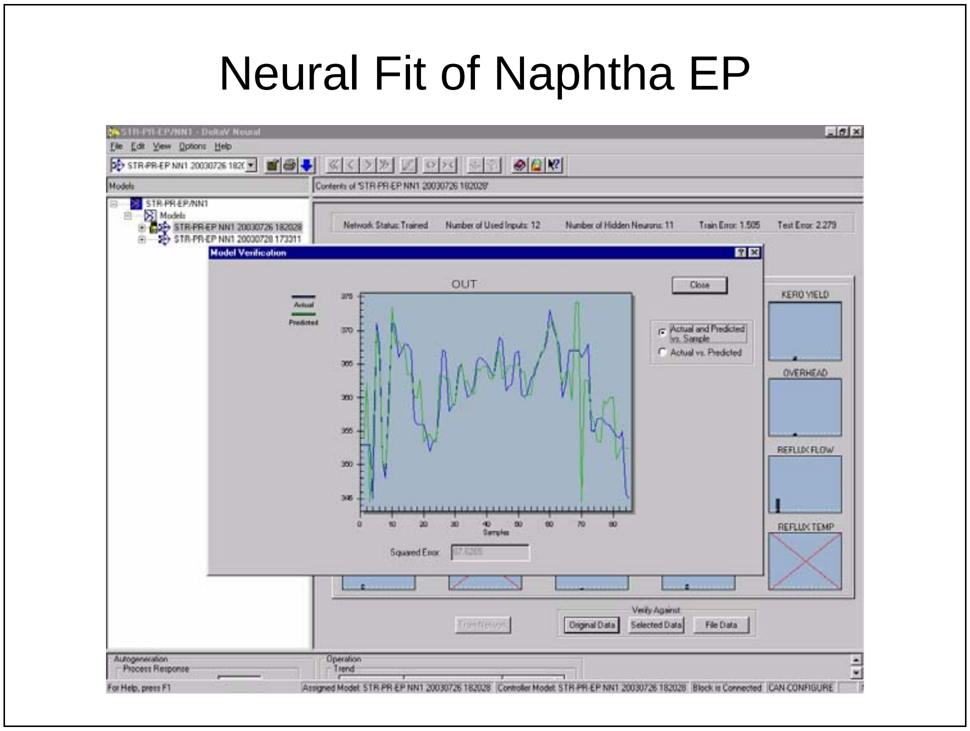

Figure 7

The operator interface to the APC functions is provided through the DCS console graphics. Key calculated variables, neural net predictions and the controller targets can be viewed through the main process overview displays. Detailed information on the MPC blocks is provided by standard MPC Operate displays that are automatically configured from the block configuration. These displays include the following five main windows as shown in Figure 8 below for the Atmospheric Column:

- Controller Mode Window
- Trend Window
- Controller Status Window
- Variable Faceplace Displays
- Detailed Faceplate

All operator interaction can be accomplished through these screens including changing controller modes, setpoints and limits.

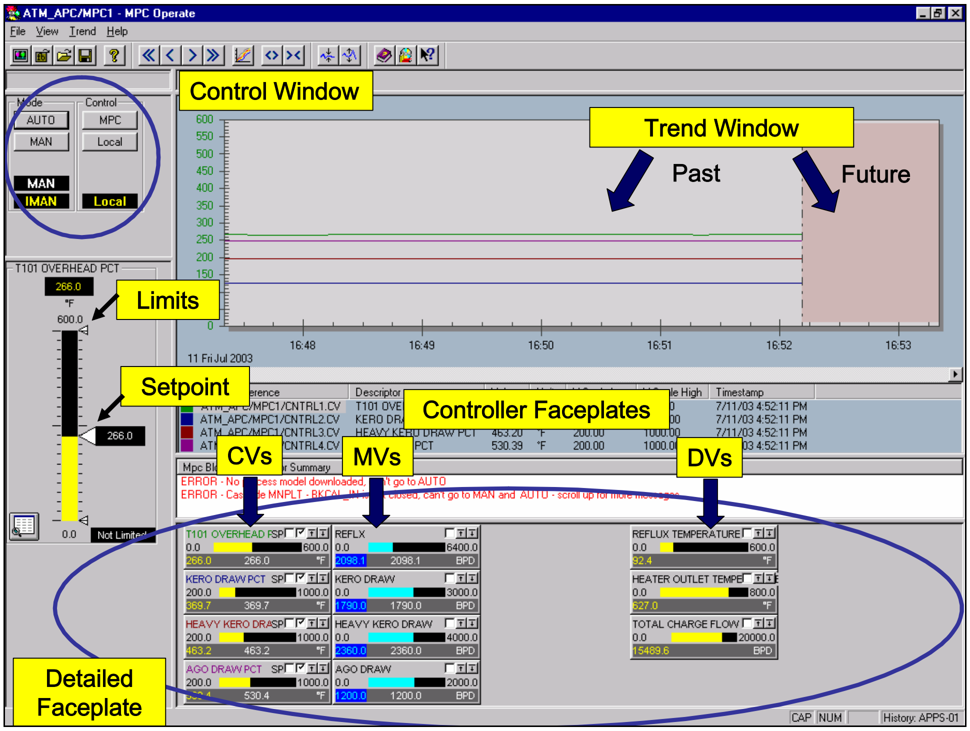

**Figure 8
MPC Operate Display**

Overall, the step tests, model identification and validation activities for both the Atmospheric and Vacuum Columns were completed in slightly less than ten days. The advanced control functions were commissioned in a week in July, 2003 a few days after the step tests were completed. Within two days, both controllers were on and controlling temperatures as designed. Subsequent changes to the controller design were implemented primarily by Ergon's own control staff and the final Site Acceptance was completed in August, 2003. The following table shows the calendar time associated with each project phase.

Activity	**Timeframe**
Functional Design Specification	3 weeks
Application Configuration	< 1 day
Step Tests & Model Identification	10 days
Commissioning	1 week
Site Acceptance Test	3 days

Results

Overall, operator acceptance of the new technology has been excellent, with closed-loop time essentially at 100% since it was commissioned. The controllers are able to hold the tower temperatures, for the most part, to within less than a degree from their setpoints are shown in Figure 9 below. Some excursions may occur when switching crudes, but the operators usually leave the MPC blocks in control and allow it to recover. Similar results were observed for the Vacuum Column.

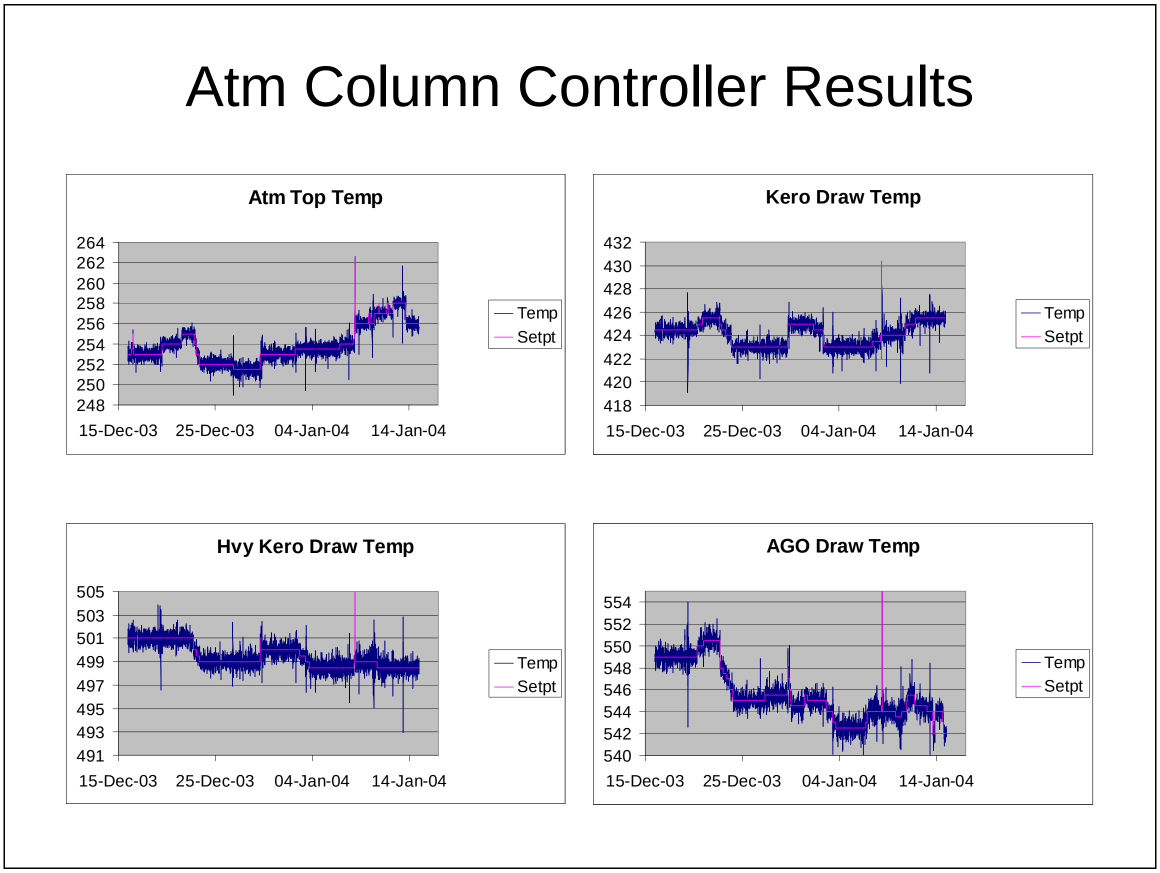

Figure 9

A comparison of process data collected before and after commissioning indicates a reduction in standard deviations for all quality variables as well as the tray temperatures. This data is provided in the table below.

	Before		After		Reduction in Std. Dev.
	Average	St. Dev.	Average	St. Dev.	
Atm Column					
SR NAPHTHA EP	353.69	5.40	339.79	4.53	16.0%
AGO EP	633.35	10.54	626.95	3.54	66.4%
OVERHEAD TEMP	263.67	3.55	253.87	1.84	48.1%
KERO TRAY TEMP	419.56	4.64	424.11	1.06	77.0%
HVY KERO TRAY TEMP	494.73	4.53	499.46	1.11	75.6%
AGO TRAY TEMP	531.13	4.52	545.57	2.45	45.8%
Vacuum Column					
WAX DIST EP	934.36	12.28	936.88	3.40	72.3%
VGO CHIMNEY TEMP	358.58	7.32	353.17	1.89	74.2%
WAX VAP TEMP	542.47	5.99	424.15	1.09	81.8%

The reduction in standard deviation of the key product qualities resulting from the new control strategy has allowed the refinery to reduce the operating target ranges set by the planning group from 10 to 6 deg. F. The improved process performance not only improves the quality of the products delivered to Ergon's customers, but allows the refinery planners to set targets that increase the overall refinery operating margins. As an example, a 4 degree F change in the Heavy Naphtha/Kero cutpoint shifts the yields about 400 BPD, which at a $2/Bbl price differential generates $280,000 in profit.

Conclusions

In the past, high implementation costs and special technical skills required to implement and maintain advanced control applications have relegated these technologies to the largest, most sophisticated refineries or petrochemical plants, which have sufficient incentives to justify such an investment. With the advent of embedded APC tools, that is no longer true today. These APC functions are now available to any process control engineer, who can learn to use them with only a small amount of training. APC applications are now feasible for even small process units with limited benefit potential. Simple regulatory functions like loop decouplers or overrides can be implemented easily and cost effectively using the built-in MPC blocks. Neural-net inferential sensor technology can be configured and tested with just a few mouse clicks. For more than 50 years, control engineers have been making do with PID, feedforward or lead/lag algorithms and high/low selectors because that is all that came with a basic control system. It is now time for APC tools to find their way into a typical control engineer's toolbox, to be used along with all the other basic control functions he or she uses on a daily basis.

For more information:

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