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Building an Effective Operator Interface for Complex APC Applications

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Abstract

To consistently use an advanced process control application, an operator must have a user interface that succinctly shows key information about the state of the plant and of the application. The interface must provide means to drill down and explore specific application behaviors. The more complex the application, the more difficult it is to provide both effective summary information and simple methods for further exploration. Effective presentation of key plant data will improve application service factor and performance.

This paper discusses operator interfaces for DMCplus and DMCplus Composite systems at ethylene plants in ExxonMobil Chemical. For plants attempting to run as full as possible, operators are particularly interested in understanding what are the current throughput-limiting constraints. The paper emphasizes display of appropriate constraint information.

Most ethylene plant DMCplus systems consist of multiple controllers and subcontrollers -- too many to watch simultaneously on individual displays. The main "entry portal" for the interface is an overview display. This overview is at a higher level than the traditional DMCplus subcontroller display because it presents information about the plant over the scope of the entire DMC/Composite system. This is the main display an operator uses to monitor the plant.

The overview indicates what section of the plant is currently limiting production. This paper presents a method of identifying the limiting area of the plant by monitoring which DMC subcontroller has more active constraints than unconstrained manipulated variables. The overview also shows when constraints have been given up, which often indicates a need for the operator to take corrective action. From the overview, the operator can navigate to the correct subcontroller display to find more information about the constraint violation. The operator can also navigate from the overview to a constraint history, or to online documentation.

Introduction

In order for an operator to consistently use an advanced process control application, he must have a user interface that succinctly shows key information about the state of the plant and of the application. The interface must also provide a means for the operator to drill down and explore specific application behaviors. The more complex the application, the more difficult it is to provide both effective summary information and simple methods for further exploration. Effective presentation of key plant data will improve application service factor and performance.

Many modern ethylene plants have implemented model-based multivariable controls as an integral part of their operating strategy. These control applications are useful for honoring a number of plant constraints simultaneously and often for maximizing throughput for a unit. However, the interfaces for these applications present information to the plant operator in a different fashion from what he is often accustomed to seeing. As the number of multivariable control applications increases, some method must be provided to show the operator the few key pieces of information he needs to make correct decisions.

Consider the analogy of an automobile dashboard. An automobile is a complex machine, but under most normal operating scenarios, there are only a few pieces of critical information that the operator/driver needs before him at all times. The automobile speed is usually displayed prominently on the dashboard because it should be monitored often; fuel level is displayed because it is occasionally checked; some other gauges and indicators are present only to warn (visibly and/or audibly) when something is wrong. The dashboard also houses controls within easy reach for a number of actions that the driver may frequently take: steering, adjusting climate controls, or setting the cruise control, for example. Similarly, in an ethylene plant, an effective interface is one that lets operators see key operating data and take common actions from one location. Identifying the key pieces of information and presenting them in a single place will help the operator to monitor the applications more effectively. Ultimately, effective monitoring is a key component of high service factor, since operators are more likely to allow the application to run when they can easily see what it is doing and why.

The behavior of a multivariable control application depends heavily on the set of constraints against which it is operating. For plants running close to full capacity, operators have a particular interest in understanding the current throughput-limiting constraints. Therefore, the appropriate "dashboard information" for such a control system should include some detail about plant constraints.

This paper is based on operator interfaces for multivariable control systems at two ExxonMobil Chemical ethylene plants: the Baton Rouge Chemical Plant (BRCP) in Baton Rouge, Louisiana, USA, and the Imperial Oil Sarnia Chemical Plant (SCP) in Sarnia, Ontario, Canada. Within ExxonMobil, Aspen DMCplus® ("DMCplus" or "DMC") software is used for multivariable constraint control. Several ExxonMobil plants (including BRCP and SCP in this paper) have implemented DMCplus Composite ("Composite") to coordinate the solutions of the individual DMC controllers in the ethylene plant and to maximize throughput. However, the information presented here should transfer readily to other commercial solutions for multivariable control and throughput maximization.

The Overview Display

Most ethylene plant multivariable control systems consist of a number of applications ("controllers" and "subcontrollers" in DMCplus), too many to watch simultaneously with a detailed individual display for each. Therefore, we have found it useful to construct an overview display to serve as a sort of "dashboard" for the entire multivariable control system. This overview is at a higher level than the traditional DMCplus subcontroller display because it presents information about the plant over the scope of the entire DMC/Composite system. This is the main display that an operator will use to monitor the plant; it generally eliminates the need for operators to page frequently through multiple displays for individual applications.

Many operators are accustomed to thinking about the plant as a sort of front-to-back flowsheet, so it may be helpful to arrange data for individual unit operations in an order that approximately mimics the flow plan for the plant.

Because every plant's operating circumstances and control system design are different, the perfect content for an overview display will vary from site to site, and the plant's operations personnel should be thoroughly consulted about their interface needs. However, there are some features that have been found helpful at both BRCP and SCP that should generally translate to other sites. These features are listed in Table 1 and are individually described below.

Table 1. Information Content for the Overview

• Status of Individual Applications	• Current Value for Major Unit Constraints
• Target Rate for Each Furnace/Feed	• Entry Mechanism for Major Operator-Entered Limits
• Current Rate for Each Furnace/Feed	• Limit Violation Indicators
• Constraint Indicator(s)	• Countdown Timer
• Production Rate Data	

Status of Individual Applications

There are a number of different controllers and subcontrollers in the complete DMCplus Composite suite. The ON/OFF statuses for each of these applications should be shown, along with each application's status in the Composite suite (i.e., participating or not). The operators might be allowed to change these statuses from this display; see more discussion on this subject in the section "Frequent Actions."

Target & Current Rates for Each Furnace/Feed

Because feed maximization is a common operator priority, and because feed comes from several cracking furnaces that may vary in their capacity and/or feed type, it is useful to display both the current feed rate and the target rate coming from the Composite feed maximizer. The current rate provides a snapshot of the current feed situation, and the target indicates the direction in which the plant will move in the immediate future. If more than one feed type is present, it is also useful to display totals for each feed type.

Constraint Indicator(s)

Especially in an environment where the operating objective is to maximize production, operators need to be able to quickly identify the throughput-limiting constraint for their feed-maximizing application. There are at least two reasons for watching the identity of this constraint: in the long-term, the plant may wish to understand its debottleneck opportunities; in the short term, operators need to consider whether every manual action has been taken that could help alleviate that constraint and thereby increase the production rate. See additional information in the section "Constraint Determination."

Production Rate Data

Displaying the plant production rate will allow operators to see how well they are meeting their production objective, whether that objective is to produce at a certain rate or to produce the maximum possible from the plant.

Current Value for Major Unit Constraints

Even when a single "throughput constraint" has been identified, operators frequently want to know how close they are operating to other key limits or constraints, which may or may not limit feed. The identity of these constraints is very plant-specific, but there is always some set that the operators monitor. If operators are accustomed to trending these limits continuously on a separate screen, there may be less need to present that information on the overview.

Entry Mechanism for Major Operator-Entered Limits

The overview display should provide a way for operators to enter key constraint limits for the control applications, especially those limits that are subject to frequent change. This will insure not only that the limits are convenient to access but also that the current values are prominently displayed so that it will be obvious if one has been set incorrectly, perhaps by a previous shift.

Limit Violation Indicators

If a DMCplus controller does not have sufficient degrees of freedom to satisfy all constraints simultaneously, one or more of those constraints will be "given up" and not honored by the solver. In such a case, the operator should be told that a constraint violation is predicted, because the operators may need to take some remedial action when the controller cannot satisfy its objectives. The specific identity of the violated constraint might or might not be displayed, but at least the operator should be told which controller contains the violation, so that he can navigate to the correct display to investigate further.

Countdown Timer

These applications run on a regular schedule. The countdown timer shows the time remaining until the next execution. It is commonly monitored to watch for the first LP solution following a change of limits or a change in the ON/OFF status for one of the controllers.

Constraint Determination

If a plant is attempting to run as close to full as possible, operators have a great deal of interest in identifying the throughput-limiting constraint for the plant. When operators know what is limiting the plant throughput, they can consider whether or not they have taken every available step outside the advanced control system to alleviate that constraint. (Manual measures might include turning on cooling water fans, turning on supplemental pumps, opening control valve bypasses where such operation is allowed, or even creeping limits associated with the constraint.)

A throughput constraint monitor also helps operators on occasions when the feed maximization application suddenly begins to reduce feed. Such reductions are often accompanied by a change in the throughput-limiting constraint. Operators may be prone to turn off advanced controls if they see a feed reduction without an obvious reason, even if the controls are later determined to have been acting appropriately. Having a throughput constraint monitor can help the operators quickly identify which constraint has come into play, without having to page through individual controller displays and try to figure out what has changed. Having a ready explanation for feed cuts helps to build confidence in the application and therefore helps its service factor.

There are several possible methods for identifying a plant's throughput-limiting constraint. The Sarnia Chemical Plant (SCP) has implemented a method which takes advantage of a feature of the linear program (LP) solver in DMCplus: at solution, in general, the number of active Controlled Variable (CV) constraints will be equal to the number of unconstrained Manipulated Variables (MV's). In other words, the problem is "square." SCP's method is to compare the number of active CV limits with the number of unconstrained MV's for each subcontroller. Ideally, one subcontroller will have an "extra" active CV that is assumed to be the constraint tying up the feed degree of freedom. Then the unit operation associated with that subcontroller is considered to be the throughput-limiting operation. The overview page for SCP identifies this subcontroller as the throughput limit. Then, if further constraint definition is required, operators can go to the subcontroller's detailed display. That page identifies which CV's are "normal constraints" (i.e., the constraints that are usually active regardless of whether or not this unit operation is feed-limiting). Then any other constraint that is active is a good candidate to be the specific throughput-limiting one. The SCP operators are familiar with the concept that DMC can honor the same number of constraints as it has degrees of freedom (unconstrained MV's), so they are used to counting constraints to see where the extra constraint appears. The constraint information in the displays simply helps them find the extra constraint more quickly.

The constraint-counting method is most straightforward to implement when each subcontroller in the overall problem is expected to be square, so that there is always an equality expected between the number of constrained CV's and free MV's in the individual applications, not just the overall problem. The use of External Targets (such as from an external optimization application) can force a CV to act constrained even if it is not at a limit, so the External Target (ET) status should be considered in the constraint count. As an additional complication, there are some circumstances under which the number of constraints might not match the number of free MV's, even in the overall solution:

- Some CV ranks may be configured to solve with a quadratic program (QP) solver rather than the LP solver.
- Some MV's may be assigned an LP cost of zero so that they have no driving force to move towards a constraint, though this is generally not a recommended practice.
- Some MV's may be configured with a "minimum move" criterion instead of a "minimum cost" criterion, so that they might or might not be used at any given time to honor a constraint.

Even in any of these circumstances, though, the constraint counting method might still be applicable if it is possible to define a "normal state" relating the number of constrained CV's to the number of free MV's, since the monitor can be driven by deviations from this state.

It is not always practical or straightforward to identify a single CV as the one and only throughput-limiting constraint. Some constraints are simple, but others require more careful scrutiny to make sure that the control system has utilized all of its available handles to relieve them. For example, suppose there is a distillation tower whose general operating objectives are to control bottoms temperature with steam and to run at the highest possible fractionation by maximizing reflux to a jet flooding limit, as measured by tower delta-pressure (DP). As feed increases to the tower, reboiler steam increases and the reflux must reduce to maintain the DP limit. As reflux decreases, the overhead temperature and the concentration of the overhead impurity will increase. Even though the tower is always at its "flooding limit," this flood limit does not become a throughput constraint until the DP limit is active in addition to either a minimum reflux limit or a maximum overhead temperature or composition limit. This is an example of an "aggregate" constraint, which requires looking for a specific combination of limits to be hit.

The Baton Rouge Chemical Plant (BRCP) constraint monitor functions somewhat like an expert system, applying a series of AND/OR rules to determine a throughput limit that is an aggregation of various constraints. The rules are evaluated using the LP solution targets rather than actual process PV's, so that the constraint indicator represents the direction that the DMC system is pushing, not necessarily the instantaneous state. In the example above, the rule would read somewhat like this:

> *IF (Tower_1 DP @ HiLimit) AND [(Tower_1 Reflux @ LowLimit) OR (Tower_1 OverheadTemp @ HiLimit) OR (Tower_1 OverheadComposition @ HiLimit)] THEN Constraint = "T-1 Capacity"*

This constraint package does not attempt to identify whether or not the limits are set at the correct values; when operators see that a particular limit is active, they are responsible for insuring that the associated limits are set as generously as possible to maximize throughput.

As with the constraint counting method, the use of External Targets in DMC can cause CV's to act constrained even when they are not at their upper or lower limits, so the External Target state should be accommodated by the rule set.

This rule-based constraint monitor has the advantage that it can describe and historize results somewhat more precisely than the constraint-counting method. However, a significant disadvantage is that it can only identify constraint sets for which a rule has been written, which makes it not useful when some new set of circumstances is encountered. The new circumstances may lead to new rules, of course, but the rules are effective only for situations that have been anticipated or observed before.

Determining the throughput constraint is more complicated when there are branches in the flow path and feeds can push constraints in both branches. In such cases, it may be useful to identify constraints in each branch. One might consider each individual furnace to be a separate branch at the head of the olefins plant; in fact, both BRCP and SCP have found it useful to separately identify and display furnace constraints for each individual furnace on the overview display and/or constraint history display, described below.

Constraint Historization

Often there is a need to know not just which constraint is active at a point in time, but which constraints have been most commonly active over some time period of interest. Therefore, it is useful to provide a separate display with constraint history information so that the operator can identify a time period and see for what percentage of that time each pre-defined throughput constraint has been active. Depending on the needs of the plant, this information might be presented for each individual CV, or for a set of aggregated throughput limits. There should be a link to the constraint history page from the overview display.

Links

The overview display is not intended to provide a detailed view of every level of the multivariable control system. It is inevitable that sometimes operators will need to see specific information not on the overview. Therefore, the overview display should provide links for easy access to this information, such as:

- detailed displays for each individual control application,
- the constraint history page,
- data on any optimization applications for the unit, and
- documentation for the control applications.

Frequent Actions

Besides just viewing information, operators also have a number of normal actions that they take that should be accommodated on the overview page. For example, there may be certain unit constraints whose limits are subject to frequent change by the operators. For a DMCplus/Composite system, individual controllers may be taken in or out of the Composite suite. Operators should be able to execute these simple actions from the overview.

Individual DMC on/off switches merit some extra consideration. While it may be common for operators to turn DMC applications on and off, it is not necessarily advisable to add this capability to the overview display. Many sites may prefer for their operators to review individual limit settings before turning on any individual application. In that case, it is preferable for the overview simply to show the on/off status with a link to the detail display, to insure that the operator must go to that display to turn the application on. Putting on/off switches on the overview suggests that this is an appropriate location from which to turn a controller on, and a tendency may develop to bypass the review of individual limits.

Summary

The service factor and performance of advanced multivariable control schemes depend in part on the operator's ability to monitor them effectively. In ethylene plants with a number of multivariable control applications, presenting key pieces of operating data and application data to the operator on a single overview display has been an effective aid to understanding the state of the plant. The ideal overview display would show statuses (ON/OFF and Composite participation) for each application, current and target feed rates for each furnace, production rate data, the countdown timer for the control execution cycle, an indication of the throughput-limiting constraint for the plant, information on a number of key operating limits, and an indication when limits are not being honored by the individual applications. The overview should provide a means for them to perform certain common actions such as changing frequently-modified limits. The overview should also provide links to more detailed information on each individual application, a constraint history detail, any optimization applications, and application documentation.

Determination of the throughput-limiting constraint can be challenging. This paper has presented two methods in use within ExxonMobil Chemical: a constraint-counting method that identifies a subcontroller with an "extra" constraint (i.e., one constraint more than the number of unconstrained MV's in the subcontroller), and an expert-system method that aggregates certain combinations of constraints from the DMC LP solution.

The ultimate users of this interface, of course, are the plant operators. Representatives of the operating organization should participate in any effort to design an interface, and they should be consulted frequently thereafter to make sure that the delivered interface meets their needs.

Notes: *The term "ExxonMobil Chemical" refers collectively to some or all of the companies affiliated with Exxon Mobil Corporation which have chemical manufacturing and/or marketing operations around the world. "DMCplus" and "DMCplus Composite" are trademarks of Aspen Technology, Inc.*