

# **MPC Implementation Methods for The Optimization of a Slow MV with Good Load Rejection by a Fast MV**

## **Advanced Application Note**

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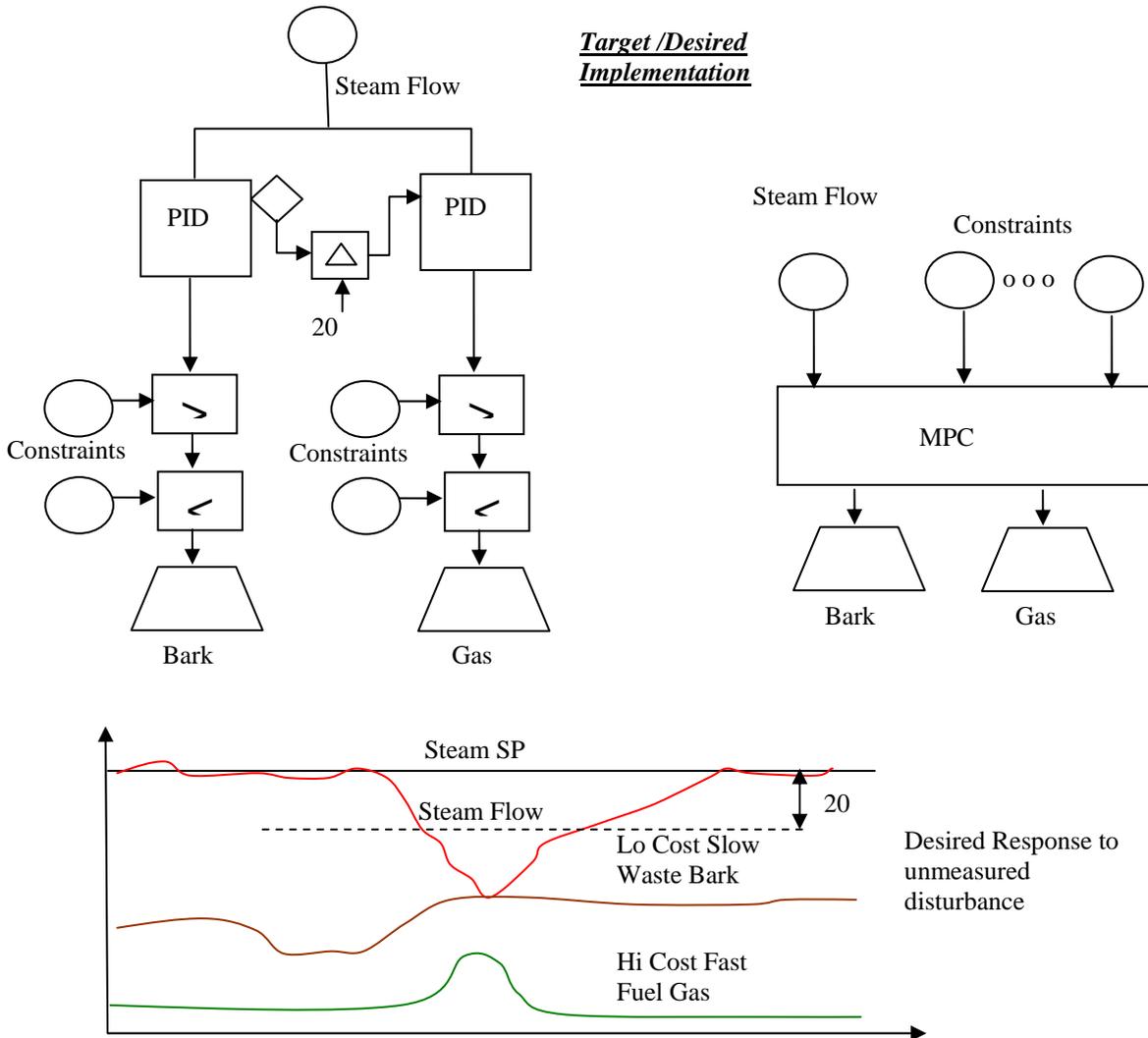
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## 1 Overview and Summary

In industrial applications it is important to reject unmeasured load disturbances and achieve a smooth optimization for maximum process efficiency. Unfortunately, the manipulated variable (MV), such as a feed, with the fastest effect on the process is often more expensive. This application note considers the use of Model Predictive Control (MPC) with one high cost fast MV and one low cost slow MV. DeltaV Predict and Predict Pro offer a MPC strategy that can readily achieve the dual objective of load rejection and optimization. The key is to set up the controller properly for maximization of the low cost MV and make a simple tuning adjustment to reduce the importance of the optimization during load rejection.

## 2 Application Examples

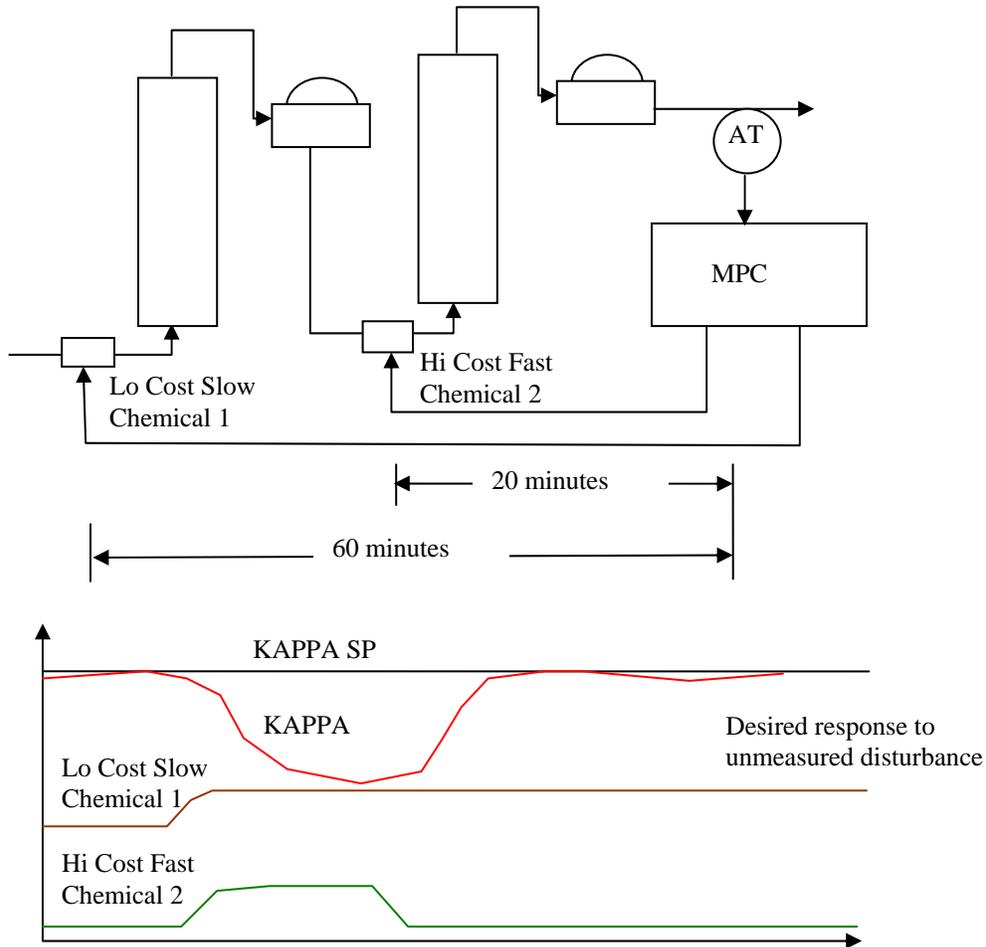
Often boilers have a waste fuel that should be maximized. However, if this fuel is a solid, there is a significant delivery delay because the solids need to be pulverized and conveyed. Even after the solids make it into the fire box, the heat release is typically slower than for natural gas or fuel oil. The example in Figure 2-1 shows the desired increase in both bark and fuel gas to compensate for a dip in steam flow.



Objective: Maximize use of bark, only use gas when required to maintain Steam SP. Steam response to change in bark is much slower than for a change in gas. Thus, bark alone may not be sufficient to address a sudden increase in steam demand.

Figure 2-1 Maximization of the Use of Bark with Use of Fuel Gas to Help Maintain Steam Set Point

The speed of response to a feed depends upon the size and mixing of intervening volumes between the point of feed introduction and the critical process measurement. In the pulp and paper industry example in Figure 2-2, the KAPPA number, which is a measure of delignification of the pulp important for brightness of the paper, is controlled by the use of low and high cost chemicals. The upstream location of low cost chemical 1 addition significantly increases the delay in its effect on the KAPPA analysis.



Objective: Maintain KAPPA target through the addition of Chemical 1 and Chemical 2. Minimize the use of Chemical 2.

Desired operation is for Chemical 2 to be used for short term correction in KAPPA to replace Chemical 2 with Chemical 1 in the longer term.

Figure 2-2 Maximization of Chemical 1 with Use of Chemical 2 to Help Maintain KAPPA Set Point

### 3 Implementation Examples

Both Predict and PredictPro can be configured and tuned for maintaining the critical controlled variable (CV), such as steam or composition, at its target and maximizing the low cost slow MV set point as an optimization variable. The best load and set point response for the critical CV is obtained with a short term tradeoff in efficiency by reducing the penalty on error (PE) for the optimization variable. When riding the low cost MV maximum set point, this PE lets both the slow and fast MV to move to improve the load and set point response of the critical CV. When riding the high cost MV low set point limit, it does not slow down the response of the other MV to upsets and set point changes to the critical CV. Only the response of the optimization variable is slowed down. This is consistent with the general theme that disturbance rejection must be fast while optimization can be slow. Figure 3-1 shows the general set up a 2x2 matrix with a critical controlled variable with a normal PE and an optimization variable with a lowered PE.

		<i>manipulated variables</i>	
		<i>High Cost Fast Feed SP</i>	<i>Low Cost Slow Feed SP</i>
<i>Maximize</i> →	<i>controlled variable</i>	<i>Critical PV (normal PE)</i> 	
	<i>optimization variable</i>	<i>null</i>	

Figure 3-1 Set Up of Matrix for Tight Control of Critical PV with Maximization of Low Cost Slow Feed

The optimization could also have been slowed down by an increase in the penalty on move (PM) on the low cost slow MV. However, a large PM forces the high cost fast MV to take most of the correction, particularly if you are riding the low cost MV maximum set point. Additionally, if you are riding the high cost MV low set point limit and the upset or set point change is in the direction requiring a decrease in this high cost MV, then the large PM makes the load and set point response noticeably slower since the response is totally dependent on the slow MV with its high PM (large move suppression).

The test results shown are for a process where the dead time is about as large as the time constant, which causes the peak error to be almost the full load upset because of the high degree of dead time. The improvement is mostly seen in the integrated absolute error (IAE). For processes where the time constant is much larger than the dead time, the reduction in peak error and IAE would be greater.

The optimization algorithm has a tight grip on the optimization variable. A large decrease in the PE helped free up the associated MV to move when it was riding its maximum set point. Setting the set point for maximization of the low cost MV higher than what is obtainable freed up this slow MV totally for upsets and set point changes that demanded an increase the MV. However, a higher than obtainable slow MV maximum forces the fast MV to its low set point limit where it is unavailable for corrections that require a decrease in the fast MV.

The alternate strategy of minimization of the high cost fast MV is not advisable for best load rejection because it would be difficult to free up this fast MV sufficiently once it becomes an optimization variable. However, if it is desirable that the minimum for the fast MV be a soft limit via an objective rather than a hard limit via a low set point limit and it is sufficient to turn over most of the load rejection to the slow MV, then this might be a viable alternative. Again, the PE must be reduced for the optimization variable.

## 4 Controller Configuration

### 4.1 DeltaV Predict

In Predict, the number of controlled variables for MPC1 in Figure 4-1a as extensible parameters is specified as 2 (NOF\_CNTRL=2). This gives two controlled variables (CNTRL1 and CNTRL2) and two manipulated variables (MNPLT1 and MNPLT2).

MNPLT1 is the high cost fast MV and MNPLT2 is the low cost slow MV. In this case, MNPLT1 and MNPLT2 are connected to the RCAS\_IN of feed flow controllers FC1-1 and FC1-2, respectively.

CNTRL1 is chosen as the critical PV with a default of “<none>” in the optimization column. The AI block AI1-1 OUT is wired to CNTRL1. CNTRL2 is the low cost slow MV and “Maximize” is chosen in the optimization column as shown in Figure 4-1b. Since an optimization strategy has been chosen, Predict knows inherently that you want to optimize MNPLT2 for CNTRL2 and will set up a pure unity gain model automatically. Note that the user does not need to wire back MNPLT2 to CNTRL2 or identify this model.

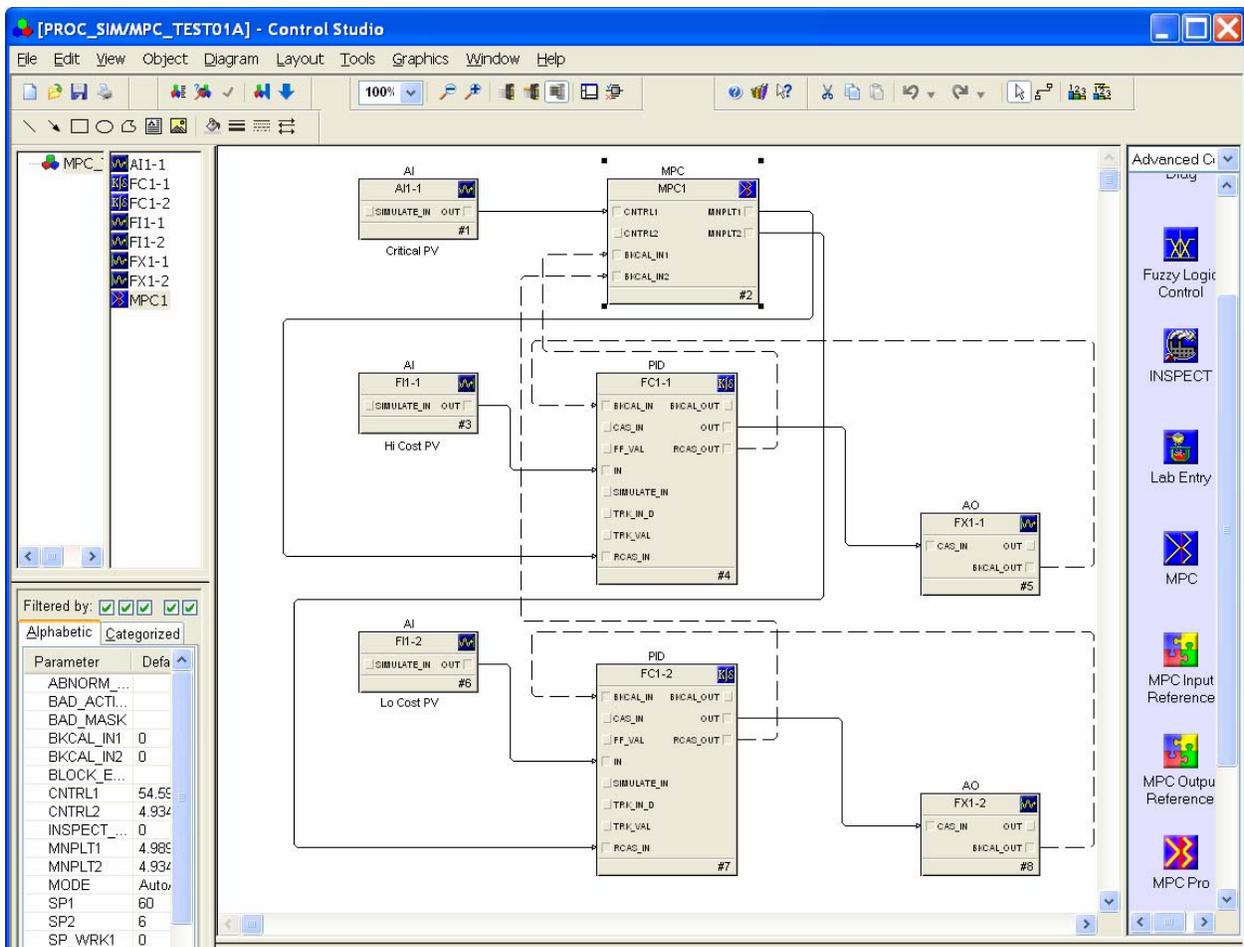


Figure 4-1a Addition of MPC Block for DeltaV Predict



### 4.2 DeltaV PredictPro

In PredictPro, the configuration as shown in Figure 4-2a is similar except the user browses to specify paths rather than wire up the MPC-PRO inputs and outputs, clicks the “<<Advanced” button to see the optimization column, selects “Target” instead of “<none>” for the critical PV, and “Maximize” for the low cost MV as shown in Figure 4-2b. Note PredictPro does not assume the PROC\_OUT2 optimization variable is MNPLT2. The user must browse to specify the RCAS\_IN of the low cost slow MV (FC1-2). Note also that RCAS\_IN and not the PV of feed flow controller must be chosen. When PredictPro sees that PROC\_OUT2 and MNPLT2 have the same path, it automatically inserts a pure unity gain model.

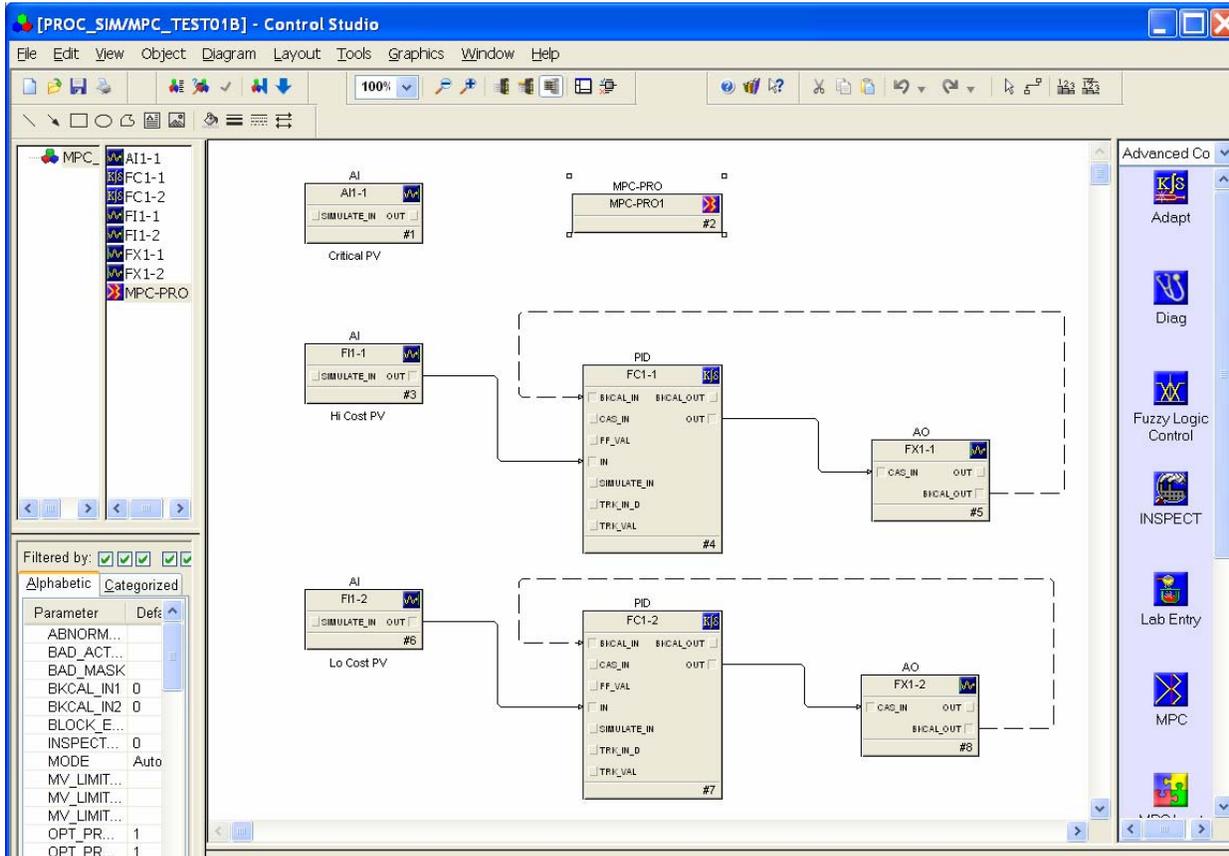


Figure 4-2a Addition of MPC-PRO Block for DeltaV PredictPro

MPC-PRO1 Properties

Name	Description	Track SP	SP Filter Time ...	SP Low Limit	SP High Limit	Path	Fail Cond...	Optimization	Priority
PROC_OUT1	Critical CV	No	0	10	100	~/AI1-1/OUT	Manual	Target	1
PROC_OUT2	Lo Cost MV SP	No	0	1	20	~/FC1-2/RCAS_IN	Manual	Maximize	2

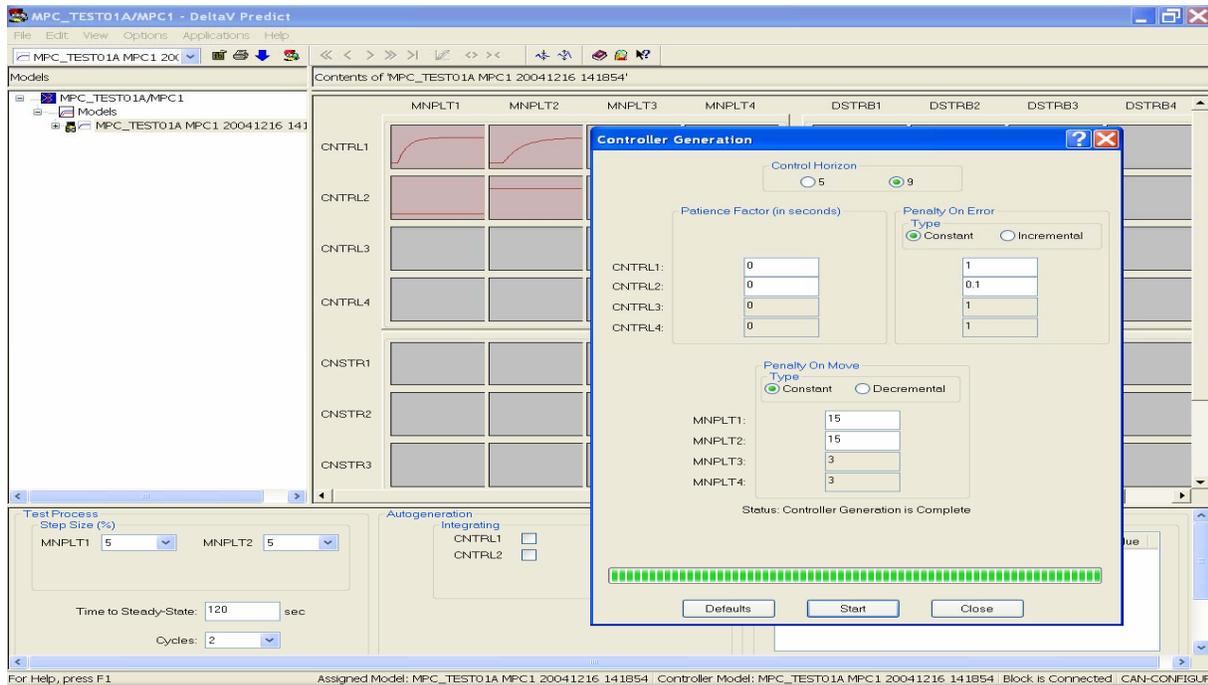
Total number of process inputs: 2      Total number of process outputs: 2      History sample rate: 1 sec

4-2b Specification of Properties for Controlled Variables in MPC-PRO Block

## 5 Controller Tuning

### 5.1 DeltaV Predict

In Predict, the Penalty on Error (PE) is significantly decreased on the “Controller Generation” screen as shown in Figure 5-1a. In this case, the PE was lowered from 1.0 to 0.1 to make the optimization of the slow MV much less important than the control of the critical PV at its target. A longer than normal control horizon was chosen to make the results of Predict closer to that of PredictPro.



5-1a Reduction in Penalty on Error of Optimization Variable for Predict Controller Generation

The trend chart in MPC Operate in Figure 5-1b shows the response for load disturbances and set point changes in both directions. In the first operating mode the low cost MV is riding its maximum set point, which leaves the fast cost MV above its low set point limit and thus free to respond in the negative as well as a positive direction. In the second operating mode, the maximum for the low cost MV has been increased to the point where it is no longer achievable, which drives the high cost MV to its low set point limit. The succession of load upsets can be so frequent that the high cost MV doesn't always ride its hard low limit, which is the case shown below. The test sequence also displays the slow response of the optimization variable to large changes in its maximum set point. It is important for operators to realize that the optimization is purposely designed to be slow and smooth and in the long term it does a great job.

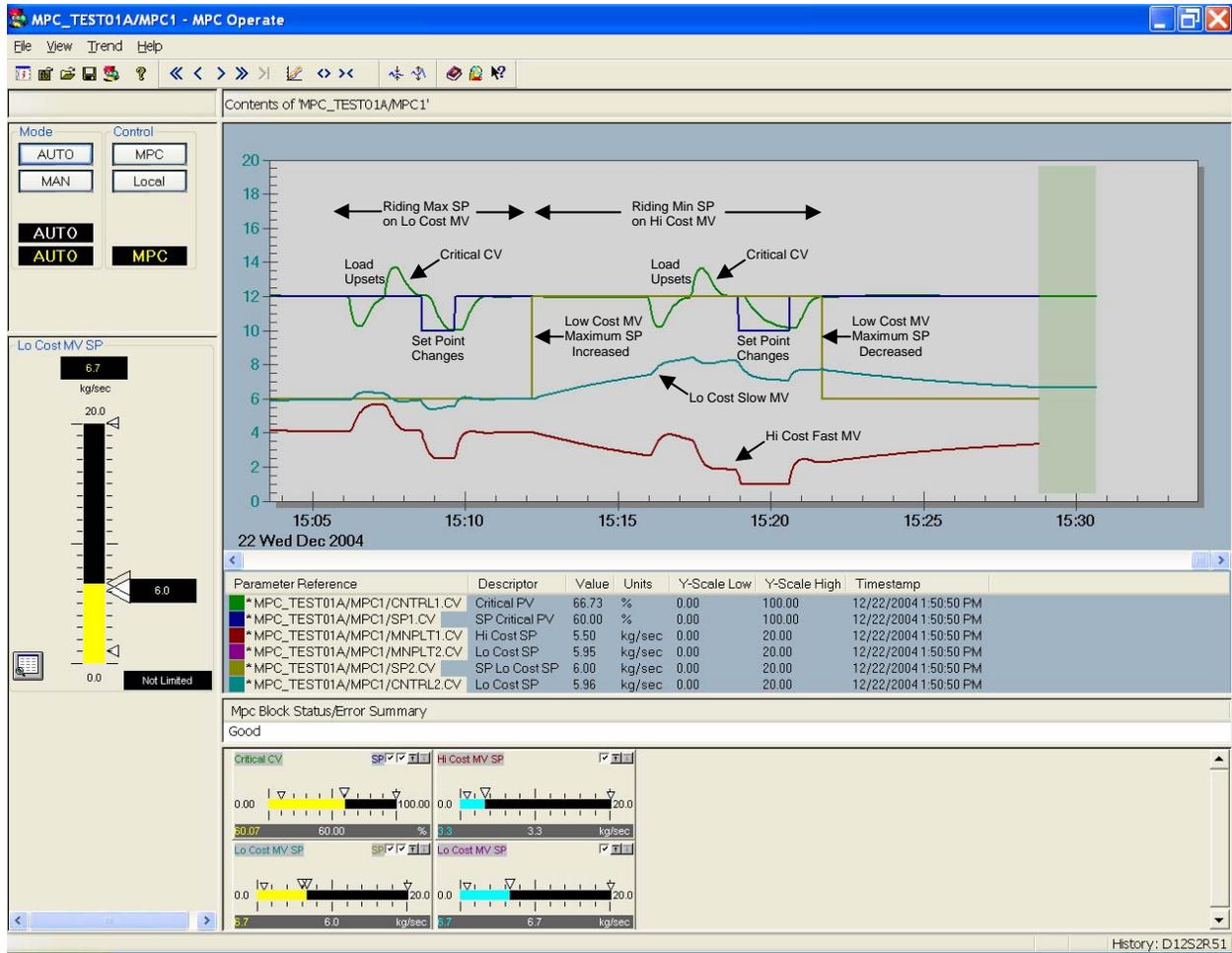


Figure 5-1b Trend in MPC Operate of Response of Predict to Disturbances and Set Points

## 5.2 DeltaV PredictPro

In PredictPro, the Penalty on Error (PE) is significantly decreased on the “Controller Generation” screen as shown in Figure 5-2a. In this case, the PE was lowered from 1.0 to 0.1 to make the optimization of the slow MV much less important than the control of the critical PV at its target.

The screenshot shows the DeltaV PredictPro software interface. The main window is titled "MPC\_TEST01B/MPC-PRO1 - DeltaV PredictPro". The "Controller Setup" window is open, showing the "Contents of Controller Setup" section. This section contains two tables:

Controlled and Constraint Variables					Manipulated Variables	
Name	Gain	DT	Current	Automatic	Manipulated	Paired Out
Critical CV	0.9999	10	X	X	Hi Cost MV SP	Critical CV
Lo Cost MV SP	0.0000	0	X	X	Lo Cost MV SP	Lo Cost MV SP

The "Controller Generation" dialog box is open, showing the "Penalty on Error" table:

Penalty on Move			Penalty on Error		
Manipulated	Current	Automatic	Controlled/Constraint	Current	Default
Hi Cost MV SP	15.00	13.00	Critical CV	1.00	1.00
Lo Cost MV SP	15.00	7.50	Lo Cost MV SP	0.10	1.00

Below the tables, there are buttons for "<= Use Automatic" and "<= Use Default". At the bottom, the "Automatic Configuration Condition Number" is 2.59339 and the "Current Configuration Condition Number" is 2.59339. The status bar indicates "Status: Controller Generation is Complete".

5-2a Reduction in Penalty on Error of Optimization Variable for PredictPro Controller Generation

It was found that moving the slider bar on PredictPro all the way to the left for maximum robustness of the optimization, gave about the same results as decreasing the PE to 0.5, whereas for this test case, a lower PE was needed to allow significant movement of the low cost slow MV for load rejection. It was also found that a set point filter on the optimization variable as large as 4 times the time to steady state did not help in achieving the stated objectives as much as lowering the PE.

The trend chart in MPC Operate-Pro in Figure 5-2b shows the response for load disturbances and set point changes in both directions. In the first operating mode the low cost MV is riding its maximum set point, which leaves the fast cost MV above its low set point limit and thus free to respond in the negative as well as a positive direction. In the second operating mode, the maximum for the low cost MV has been increased to the point where it is no longer achievable, which drives the high cost MV to its low set point limit. The succession of load upsets can be so frequent that the high cost MV doesn't always ride its hard low limit, which is the case shown below. The test sequence also displays the slow response of the optimization variable to large changes in its maximum set point. It is important for operators to realize that the optimization is purposely designed to be slow and smooth and in the long term it does a great job.

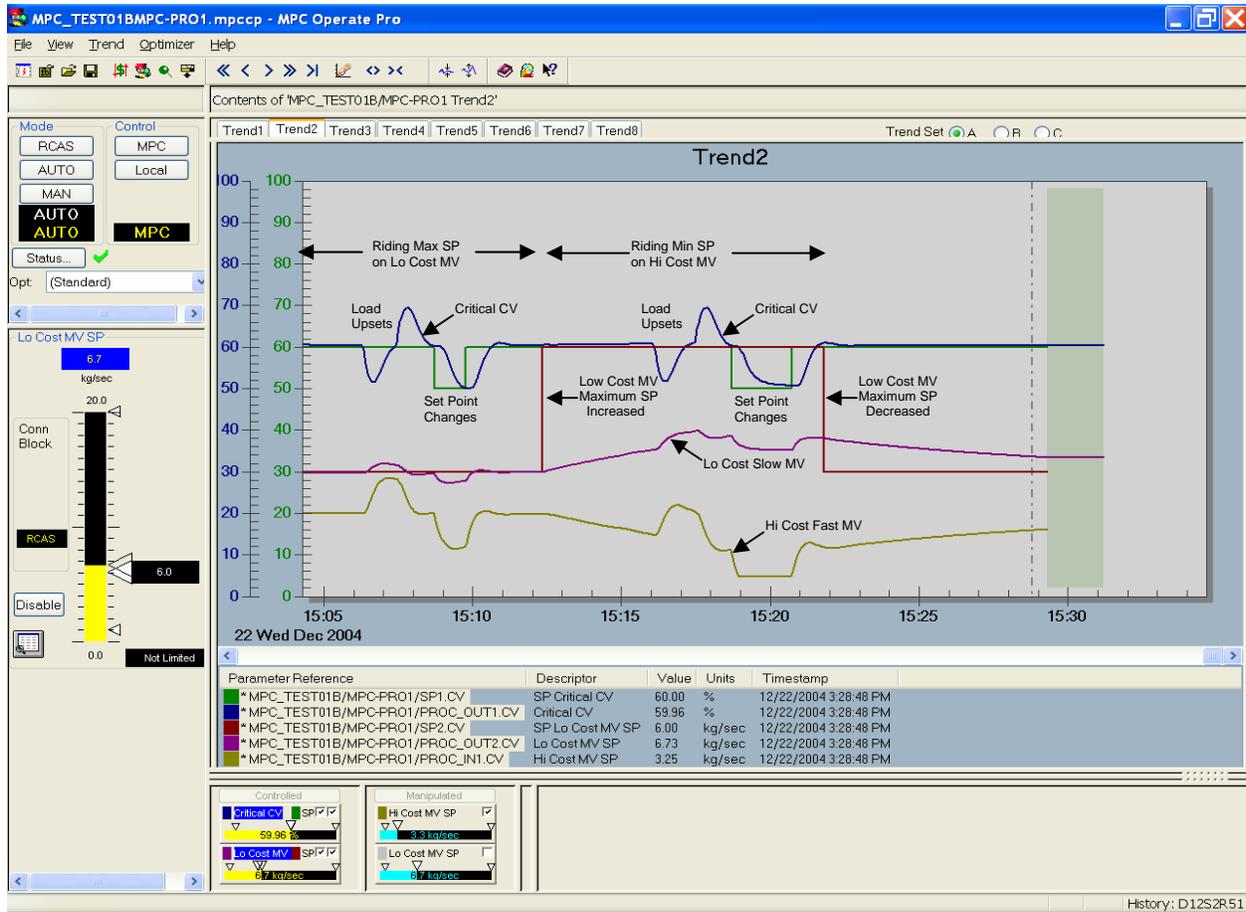


Figure 5-2b Trend in MPC Operate Pro of Response of PredictPro to Disturbances and Set Points

## 6 Discussion and Related Issues

The results in Predict and PredictPro were comparable except the bump to the critical CV for some tuning scenarios for set point changes in the optimization variable was larger in Predict than in Predict Pro. A full set of test results and the corresponding DeltaV modules are available upon request.

If the speed of optimization is more important than load rejection, then the default PE tuning is sufficient.

The minimum cost was achieved when the set point for the maximization of the low cost slow MV was higher than what was achievable so that the high cost fast MV was riding or seeking its low set point limit. In a steady state, the optimization forces one MV to ride its limit. For a slow optimization, each MV can be in transition and both are free to respond for best load rejection. Many applications show this behavior.

Note that the set point for the maximization of the optimization variable, which is the low cost slow MV, is a soft limit that can be violated by tuning, whereas, the low set point limit on the high cost fast MV, is a hard limit. This hard limit must be judiciously set because it determines both long term efficiency and short term response. If it is set below the rangeability limit of the associated measurement or final element or causes the valve to ride the seat, variability is introduced into the process from erratic response, low sensitivity, and high stick-slip. The closure of a final element can pose additional problems. A closed gas valve can cause flame instability in some burners and a closed reagent or reactant valve can cause a tremendous increase in dead time from the back filling of dip tubes and injectors with process fluid. Notice that in the application examples, the high cost fast MV is running significantly above zero.

If it is desired that the minimum set point for the high cost MV be a soft limit so that it can help with the short term rejection of upsets that require a decrease in this MV, the MPC module can be revised and the low set point limit of this high cost MV lowered. For the configuration and tuning of this strategy to temporarily operate below the desirable measurement and throttle range and the MPC implementation of notch gain, split range, and trim valve control, see the advanced application note titled "MPC Implementation Methods for the Optimization of the Response of Control Valves to Reduce Variability".