

“Get the Design Right, the Rest is Automatic” An Adaptive MPC Technology

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1. Introduction

- MPC has brought significant benefits in the refining/petrochemical industry. It has also attracted interests from other industries
- The cost of MPC deployment and maintenance is very high due to its technical difficulties and long plant test time
- An adaptive MPC is introduced to solve the high cost problem
- Using the adaptive MPC, the scarce MPC expert is only needed for controller design
- The commissioning and maintenance can be done automatically under the supervision of the operator
- Nonlinear MPC control is achieved using multiple or LPV models.

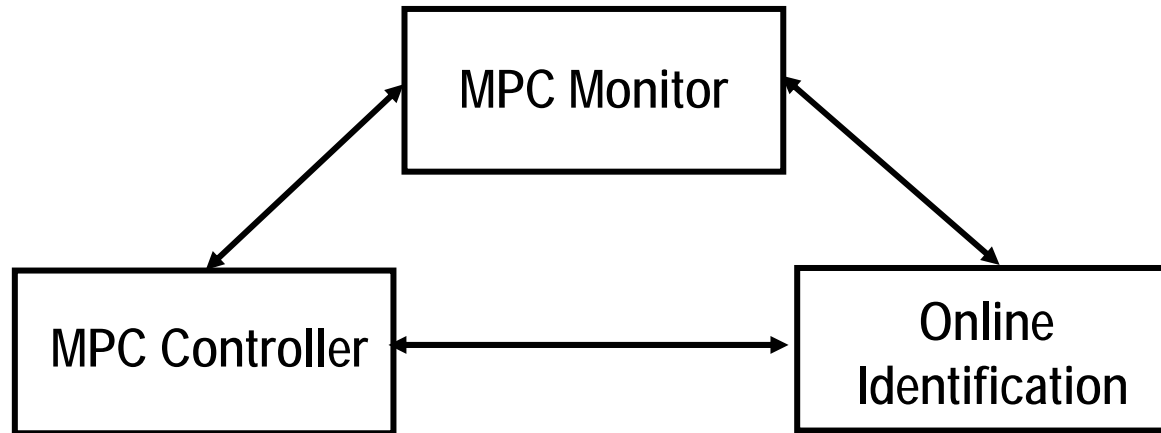
1. Introduction (Cont.)

Traditional Project Approach to Industrial MPC

1. Controller design and benefit study (10%)
2. Pre-test (10%)
3. ***Plant (step) test and model identification (40%)**
4. Controller simulation and tuning (15%)
5. Controller commissioning and operator training (25%)
6. ***Controller maintenance (mainly re-identification)**

2. The Architecture of the Adaptive MPC

- Integration is the philosophy behind the technology — there are **three** modules in the adaptive MPC



- Online automatic (open and closed-loop) identification and automatic controller tuning make the adaptation possible
- Steps 2 to 6 can be performed automatically

2.1 Online Identification Module

- Testing device
 - Perform automated multivariable test
 - Test can be open loop and/or closed-loop
 - Data collection
- Model ID device
 - Automated data pre-processing and model identification
 - Automated model validation and selection
 - Send good models to MPC Controller Module

2.2 MPC Controller Module

MPC parameter auto-tuning

- Dynamic control parameters can be auto-tuned
- Auto-tuning based on the model and data
- Tuning aims at good and robust control, though not optimal
- Economic optimization parameters are given in design

MPC control algorithms

- Steady state optimization: priorities, weights, IRV, LP&QP
- Dynamic optimization/control: QP, CV reference curve
- Can change model dynamically, necessary for nonlinear MPC

2.3 MPC Monitor Module

- Monitor CV variances for control performance
 - CV variances are compared to their benchmark variances
 - CV setpoint changes are excluded in the calculation
- Monitor MV/CV on/off status for control performance
- Monitor CV simulation error variances for model quality
 - Error variances are compared to their benchmarks
 - Test signal (excitation) may be used.

3. How Does the Adaptive MPC Work?

MPC Commissioning

Given an MPC design for a process unit:

- Set up the communication between the DCS and the PC
- Start identification test and online identification; models are created automatically at a given interval or by a mouse click
- Good quality models will be used in the MPC controller while test is ongoing
- When most (or all) expected models are with good quality, the plant test is stopped and the MPC is commissioned.

3. How Does the Adaptive MPC Work (Cont.) ?

MPC Maintenance

- MPC Monitor continuously monitors the MPC performance
- When model mismatch becomes too large, the MPC Monitor will activate online identification in closed-loop
- Models are created automatically at a given interval or by a mouse click
- Good quality models will replace the old ones in the MPC controller while test is ongoing
- When most or all poor models are identified and replaced, the maintenance is done.

3. How Does the Adaptive MPC Work (Cont.) ?

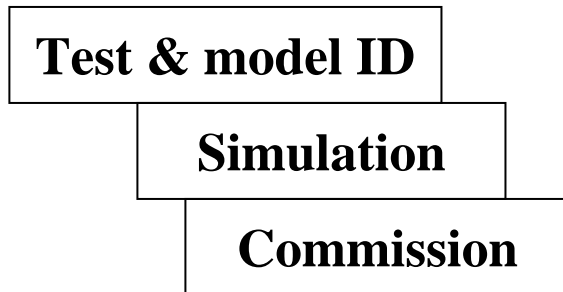
The Old Way: Series steps, 3 to 4 software packages

Pre-test	Step test & model ID	Simulation	Commission
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The “New” ID: Series steps, 3 to 4 software packages

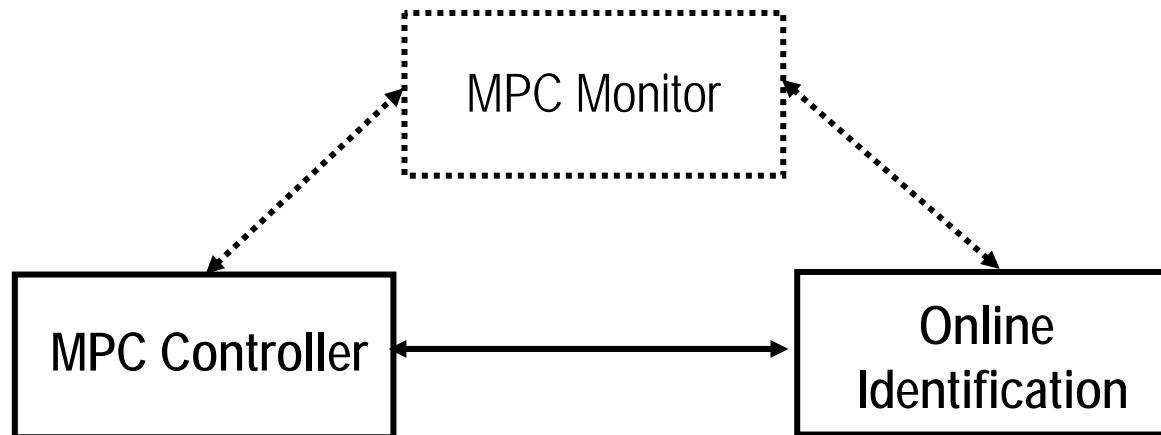
Test & model ID	Simulation	Commission
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The New Way: Parallel procedure, 1 package



4. Software Implementation

- Two modules are implemented: Controller and Identification
- Can use multi-model and LPV model for nonlinear MPC.



Configuration: Specify general items

The screenshot shows the 'Taiji MPC' configuration window with the 'General' tab selected. The window title is 'Taiji MPC - C:\TaijiMPC1.17\TaijiMPC\bin_NEW0.ojp'. The menu bar includes 'File', 'View', 'Tools', and 'Help'. The toolbar contains icons for file operations and help. The main configuration area is divided into several sections:

- Datasource:** Includes radio buttons for 'OPC', 'CIMIO', 'PHD', and 'OTHER'. The 'OPC' option is selected. Below are text boxes for 'Remote host name' and a dropdown for 'OPC server name' (currently showing 'PSII.OPC.1').
- Times:** Includes a 'Sampling Time' field with a value of '1' and a unit dropdown set to 'minutes'. Below is a 'Time to steady state, 4*tau' field with a value of '120'.
- MV Extension:** Features a checked 'Enable extension' checkbox. It contains text boxes for 'OP' (.OP), 'SP' (.SP), 'PV' (.PV), and 'MODE' (.MODE). A note states: 'MV writable mode (use semi-colon delimited list, * always enable wrote)'. There is also a text box for a wildcard '*'.
- Watch dog:** Includes a 'Use watch dog' checkbox (unchecked), a 'Value' field (180), and a 'Tag name' field (MPCWATCHDOG).
- Enable DCS start MPC:** Includes an 'Enable' checkbox (unchecked) and a 'Tag name' field (MPCSTARTCONTROLLER).
- DCS MPC Interface Extension:** Features a checked 'Enable DCS Interface' checkbox. It contains text boxes for 'CONTROL ON/OFF' (.ONOFF), 'ON/OFF STATUS' (.STATUS), 'HEIGHT(MV_CV)' (.HI), 'LOW(MV_CV)' (.LO), 'STEADY STATE(MV_CV)' (.TARGET), and 'SETPOINT(CV only)' (.SETPOINT).
- Options:** Includes three checked options: 'Automatically start identification model ID interval(>=60 min)' (120 minutes), 'Automatically use model in controller' (with an unchecked 'Clear older model in controller' sub-option), and 'The plant is a real process.' (with a 'Time Compression Factor(>=1)' field).

The status bar at the bottom left shows 'Ready'.

Configuration: Specify MVs, DVs and CVs

The image displays three sequential screenshots of the TaiJi MPC software interface, showing the configuration of different process variables.

Top Screenshot: MVs Configuration

The interface shows the 'MVs' tab selected. The table below lists the configured Moving Variables (MVs):

	MV tag name	Hight limit	Average	Low limit	Current value	Amplitude	Description
1	MV1	5	3.509	-5	3.509	1	
2	MV2	5	1.6	-5	1.6	1	
3	MV3	5	1.807	-5	1.807	1	

Middle Screenshot: DVs Configuration

The interface shows the 'DVs' tab selected. The table below lists the configured Disturbance Variables (DVs):

	DV tag name	Current value	Description
1	DV1	-0.6788	
2	DV2	0.2222	

Bottom Screenshot: CVs Configuration

The interface shows the 'CVs' tab selected. The table below lists the configured Control Variables (CVs):

	CV tag name	Hight limit	Low limit	Current value	MV-VALV/No delay	Integral	Calculated	Calculated function	Description
1	CV1	0	-5	-33.82	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		
2	CV2	5	-5	-40.23	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		
3	CV3	20	-20	-9.636	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		
4	CV4	20	-20	-5.585	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		
5	CV5	20	-20	-1.588	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		
6	CV6	20	-20	-6.838	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		
7	CV7	5	-5	-28.07	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		

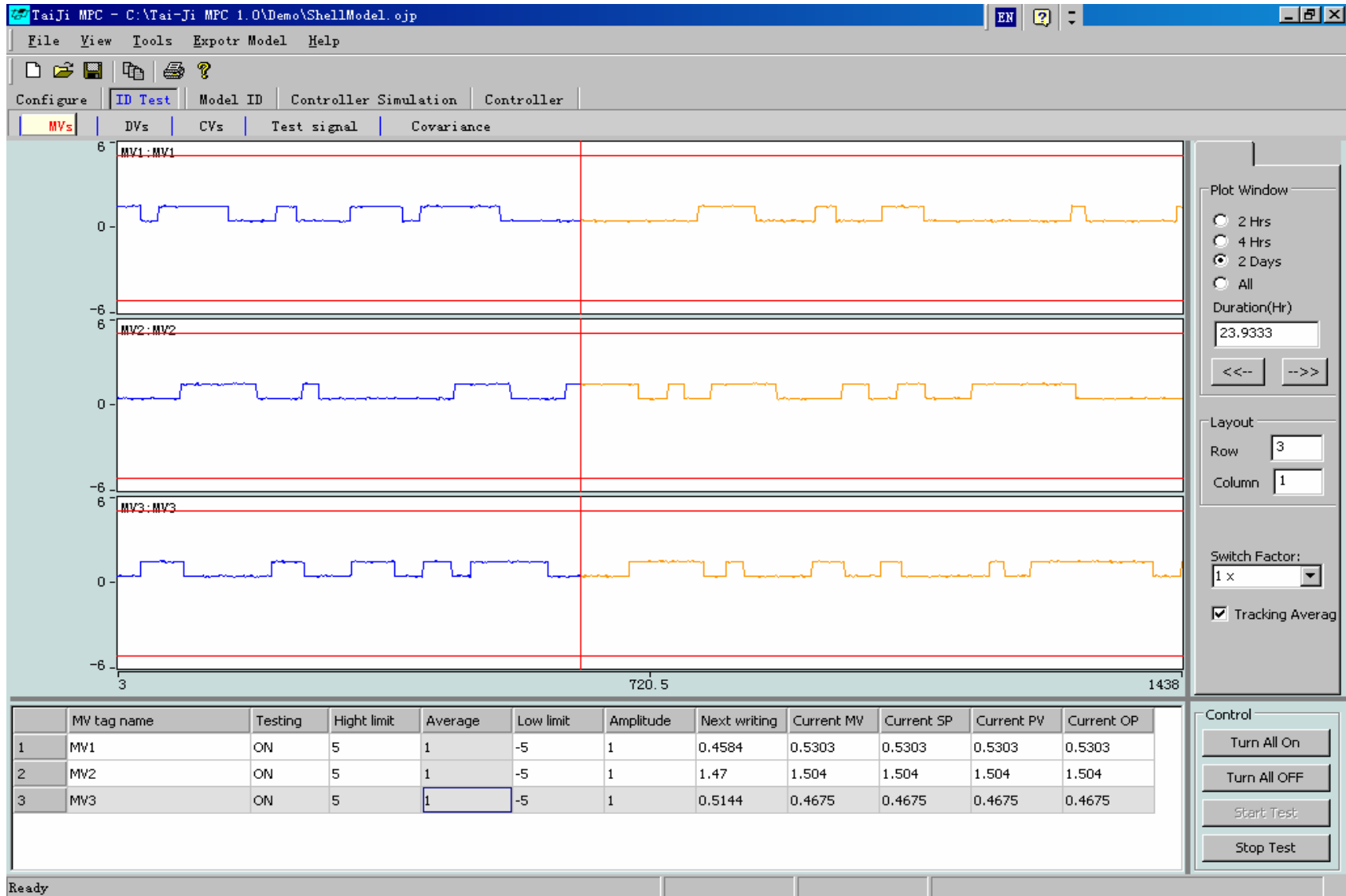
Configuration: Specify Expectation Matrix

The screenshot shows the 'Expectation' tab in the TaiJi MPC software. The window title is 'TaiJi MPC - C:\Tai-Ji MPC 1.0\Demo\ShellModel.ojp'. The menu bar includes 'File', 'View', 'Tools', 'Expotr Model', and 'Help'. The toolbar contains icons for file operations and help. The 'Expectation' tab is active, showing a table with 7 rows and 6 columns. The columns are labeled 'MV1: MV1', 'MV2: MV2', 'MV3: MV3', 'DV1: DV1', and 'DV2: DV2'. The rows are labeled 'CV1:CV1' through 'CV7:CV7'. The table contains the following data:

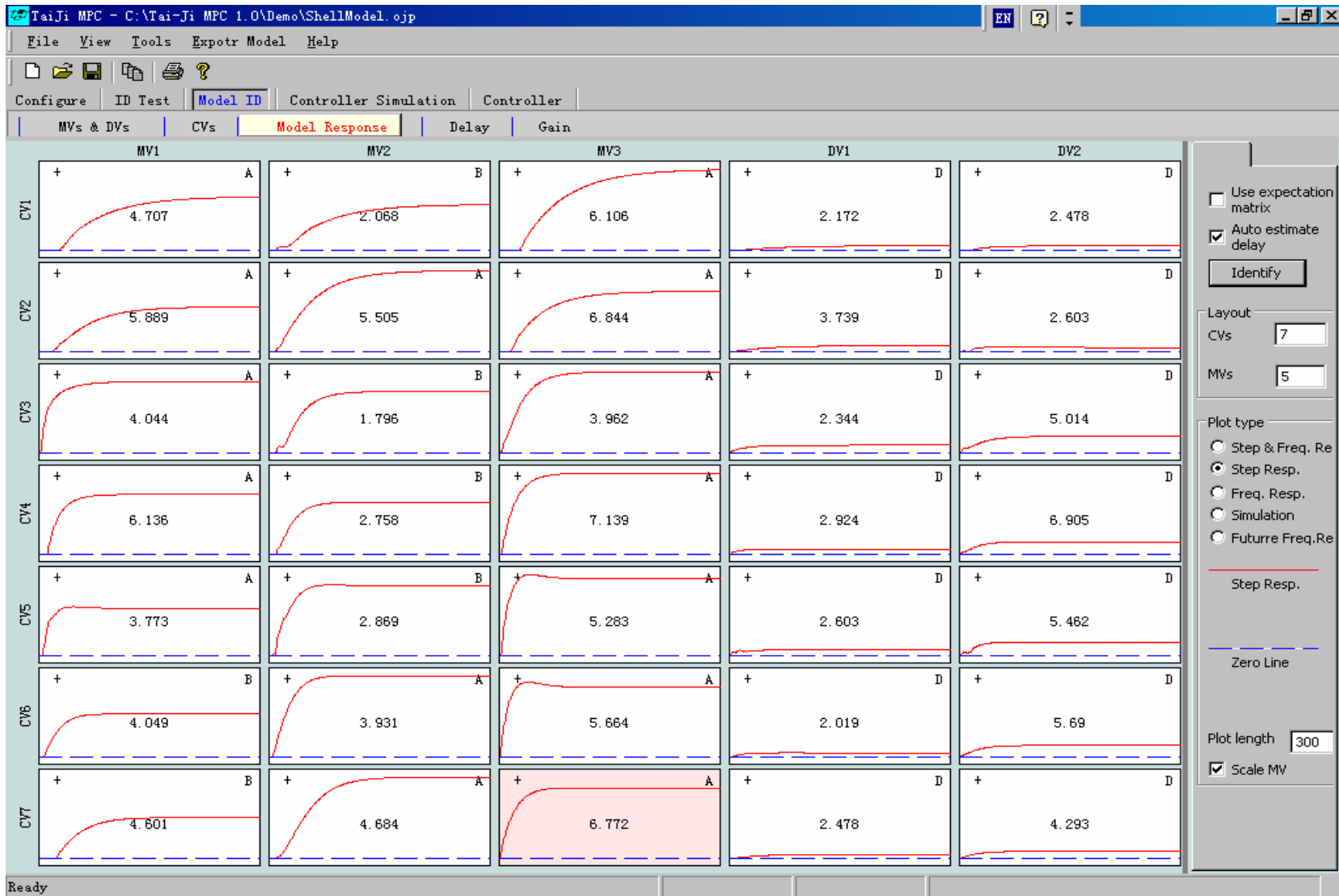
	MV1: MV1	MV2: MV2	MV3: MV3	DV1: DV1	DV2: DV2
CV1:CV1	+	no	+	?	+
CV2:CV2	+	+	+	+	+
CV3:CV3	+	+	+	+	?
CV4:CV4	+	+	+	+	+
CV5:CV5	+	?	+	+	+
CV6:CV6	+	+	+	+	+
CV7:CV7	+	+	+	+	+

The status bar at the bottom left shows 'Ready'.

ID Test, MV plots

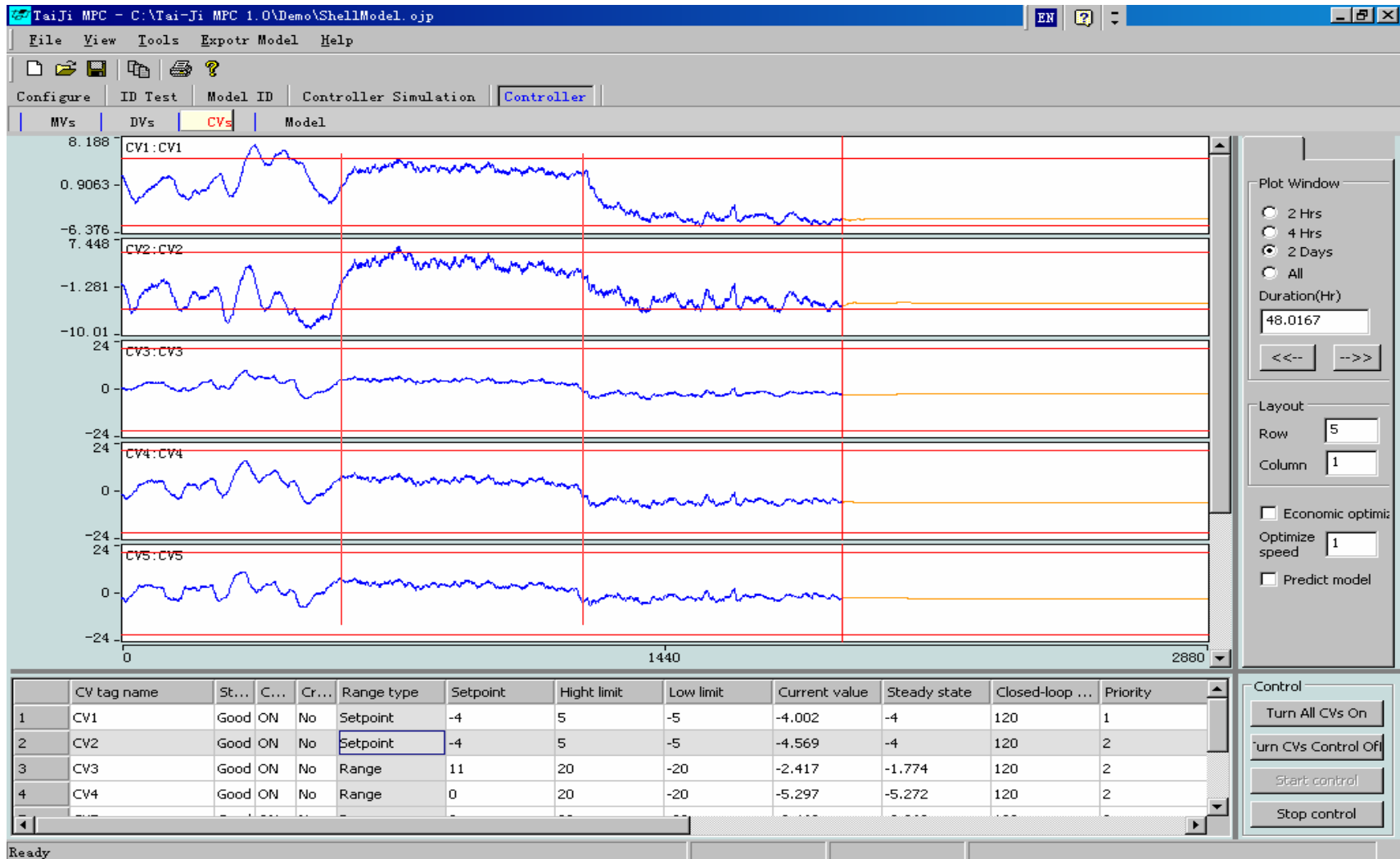


Model step responses



Controlled CVs:

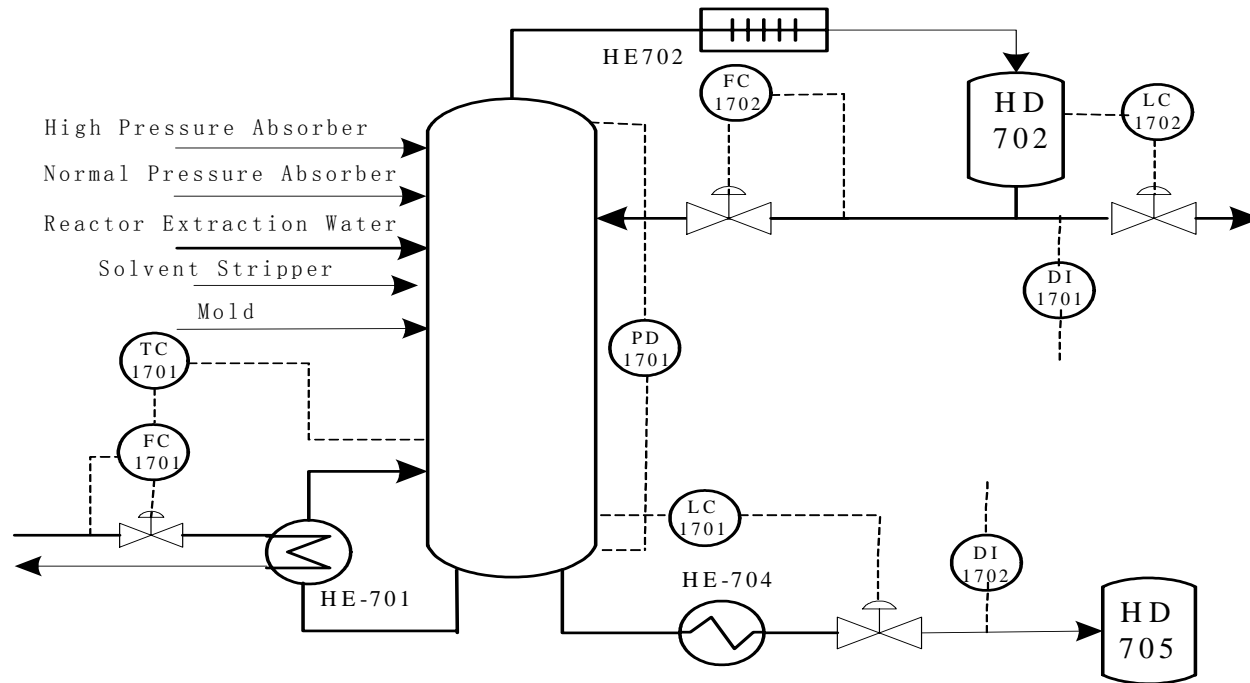
- 1) ID test on;
- 2) ID test stopped;
- 3) CV1 and CV2 changed setpoints



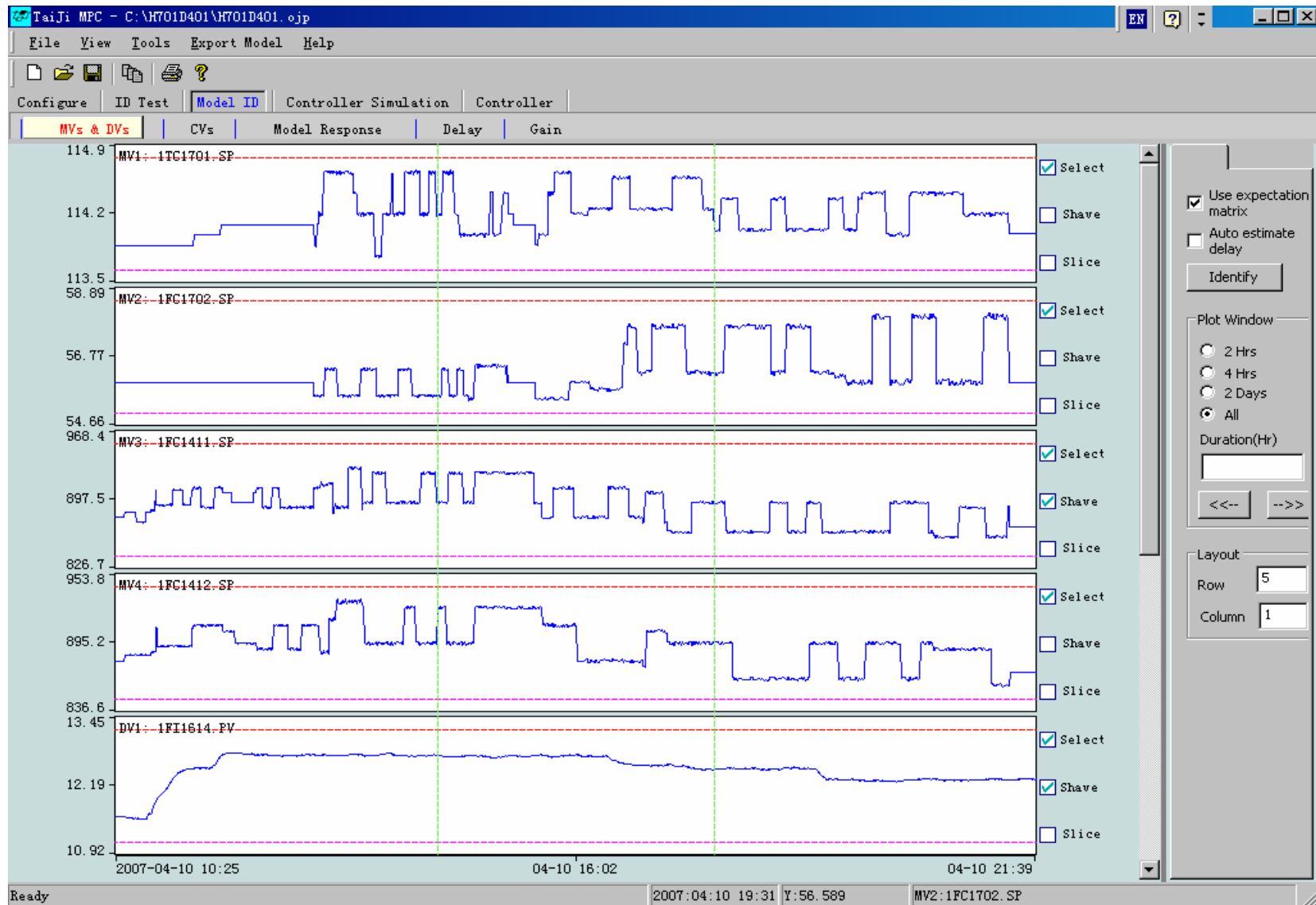
5 Application to a PTA Unit

1) Solvent Dehydration Tower

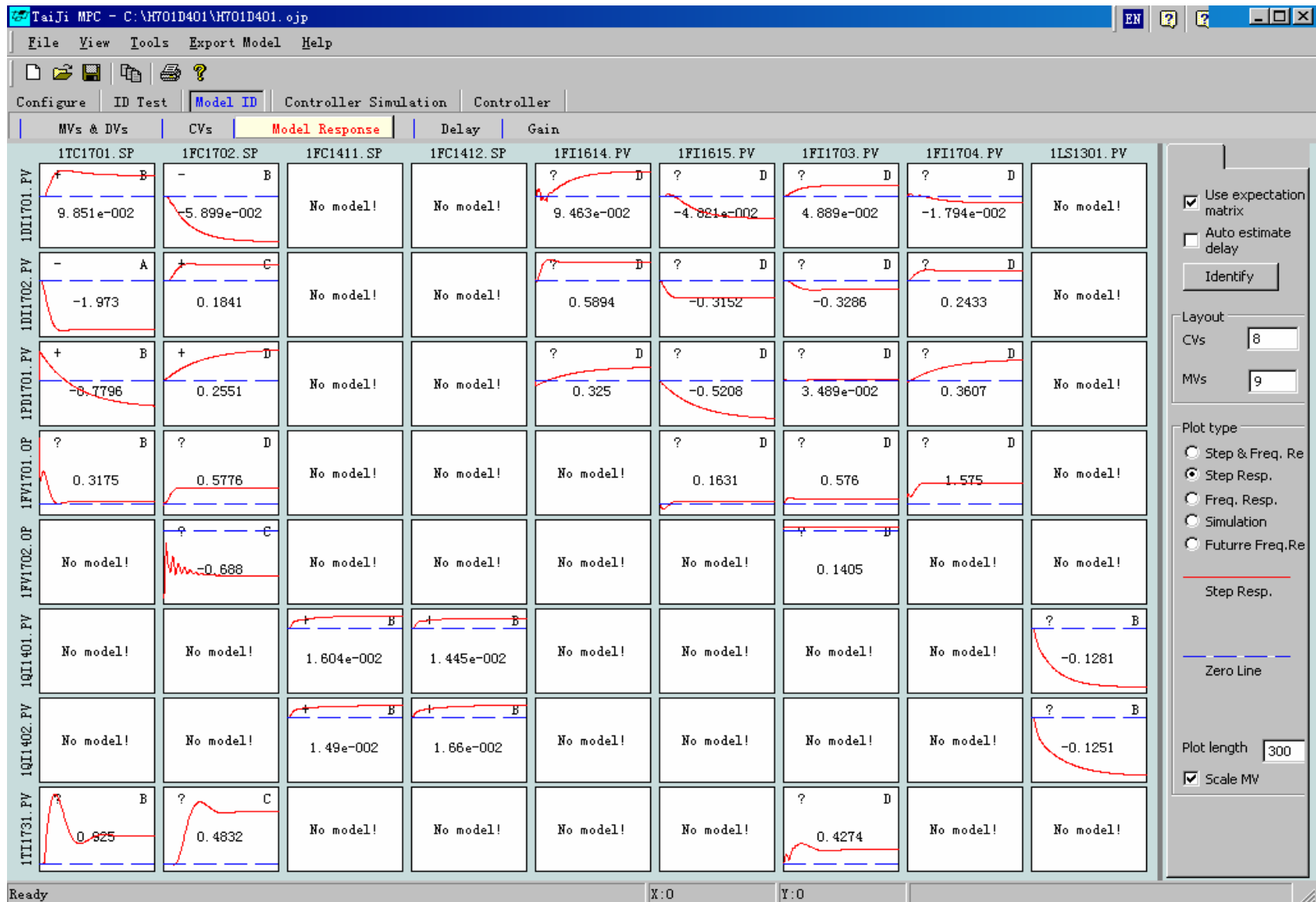
Controller commissioned after 10 hours of test



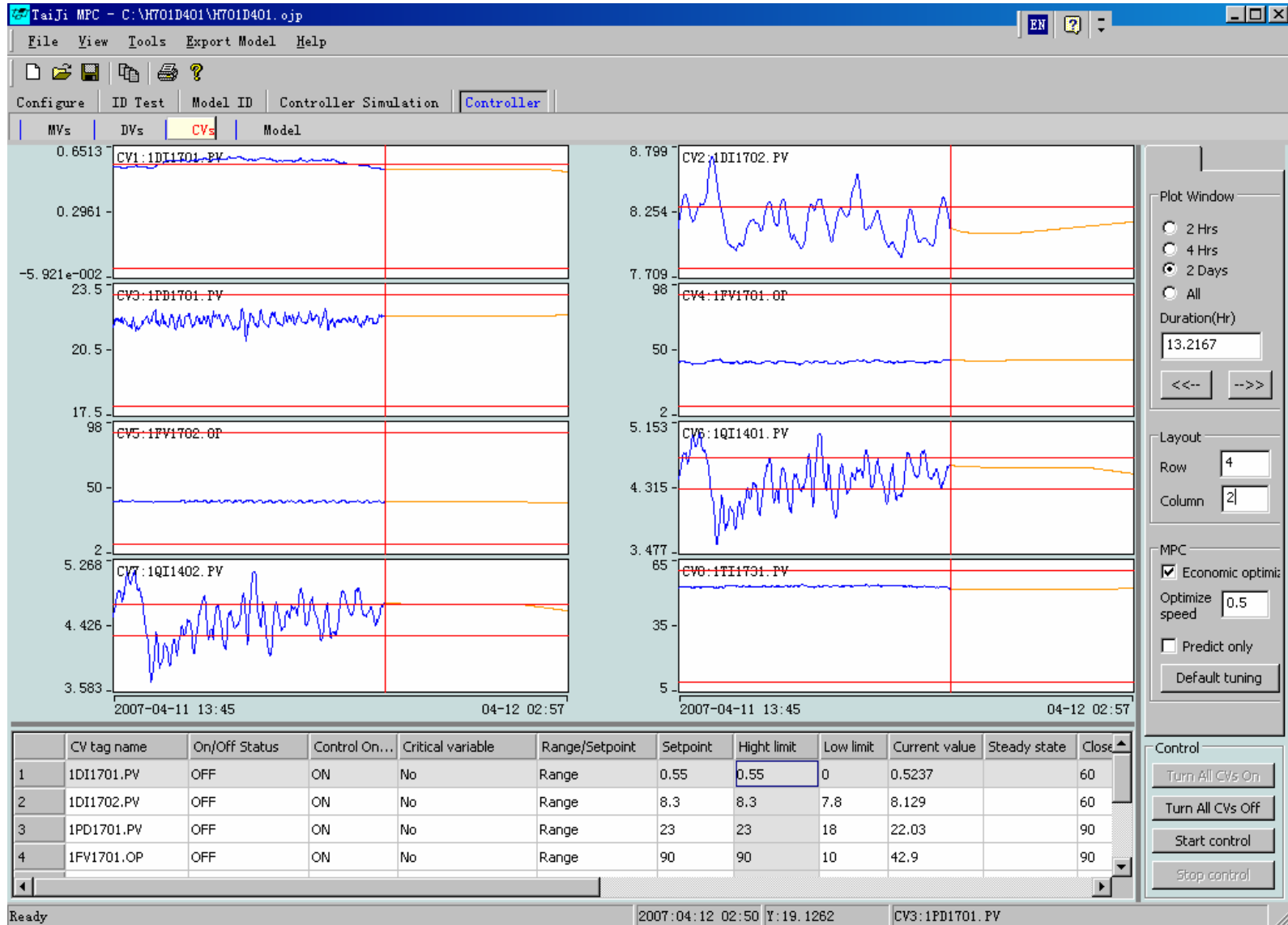
MV Signals during plant test



Model step responses



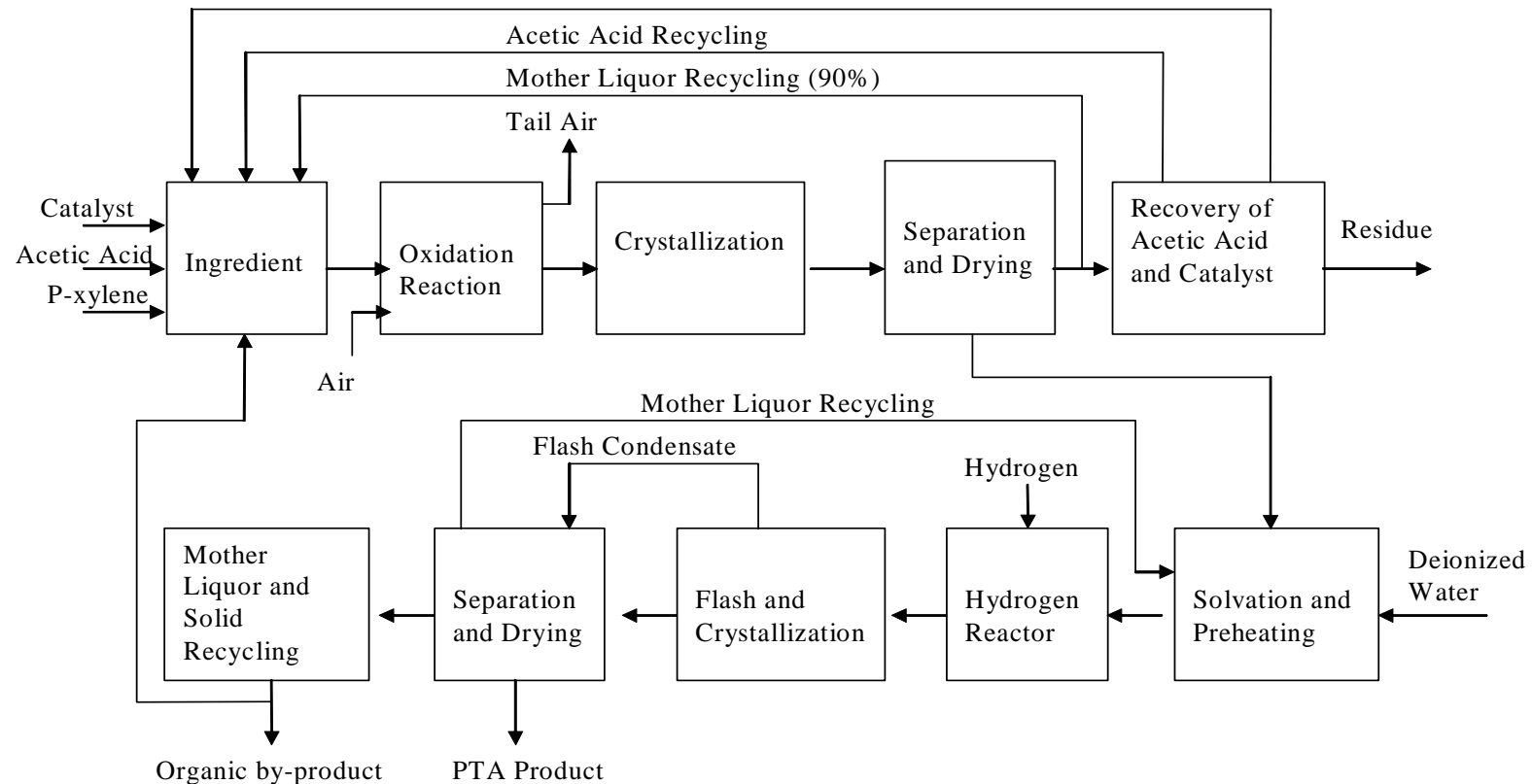
CV responses after MPC turned on

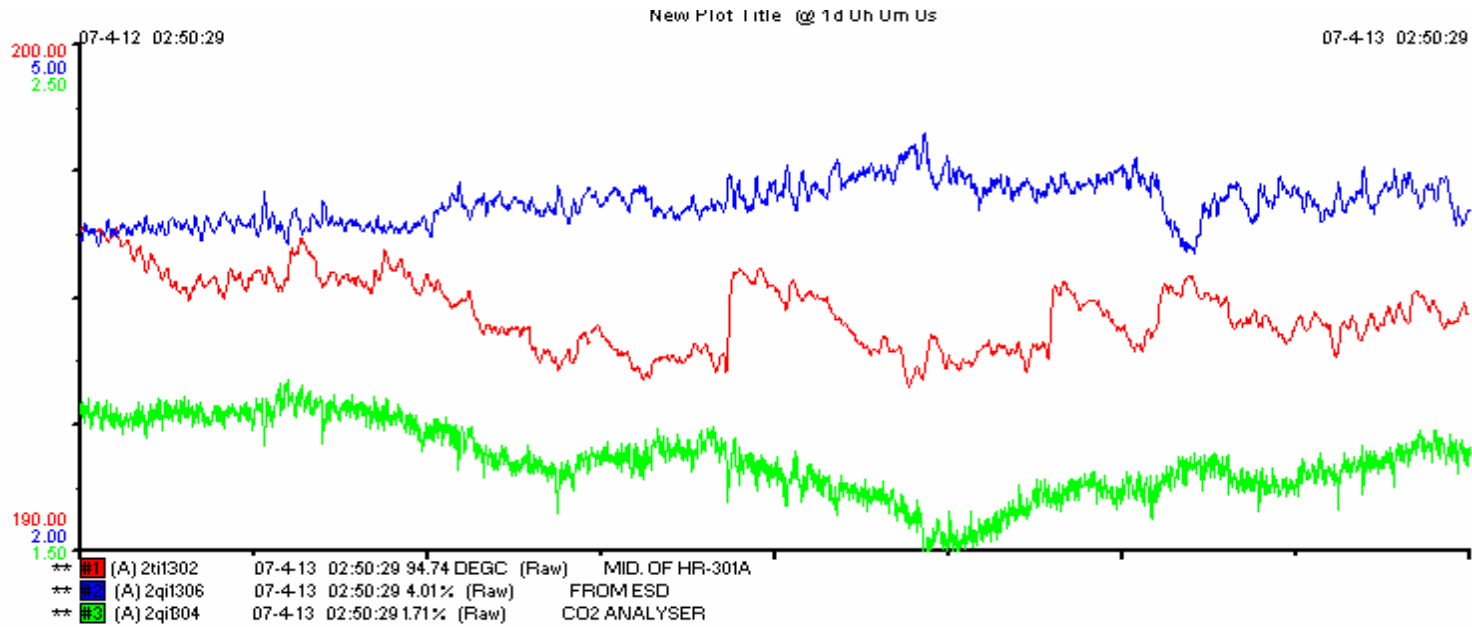


5 Application to a PTA Unit (Cont.)

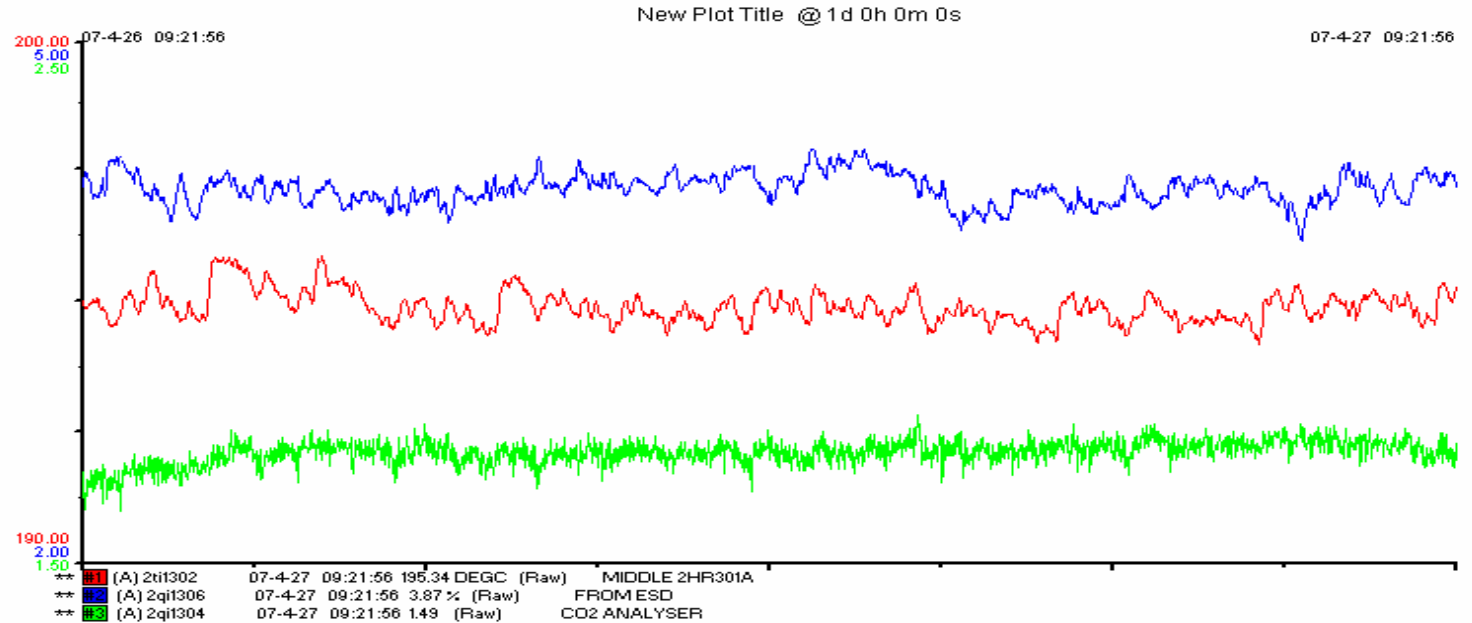
2) Reaction Section

- MPC has 16 MVs, 1 DV, 18 CVs; 3 x 10 hour tests used
- Control OK; some closed-loop test/ID can improve model quality

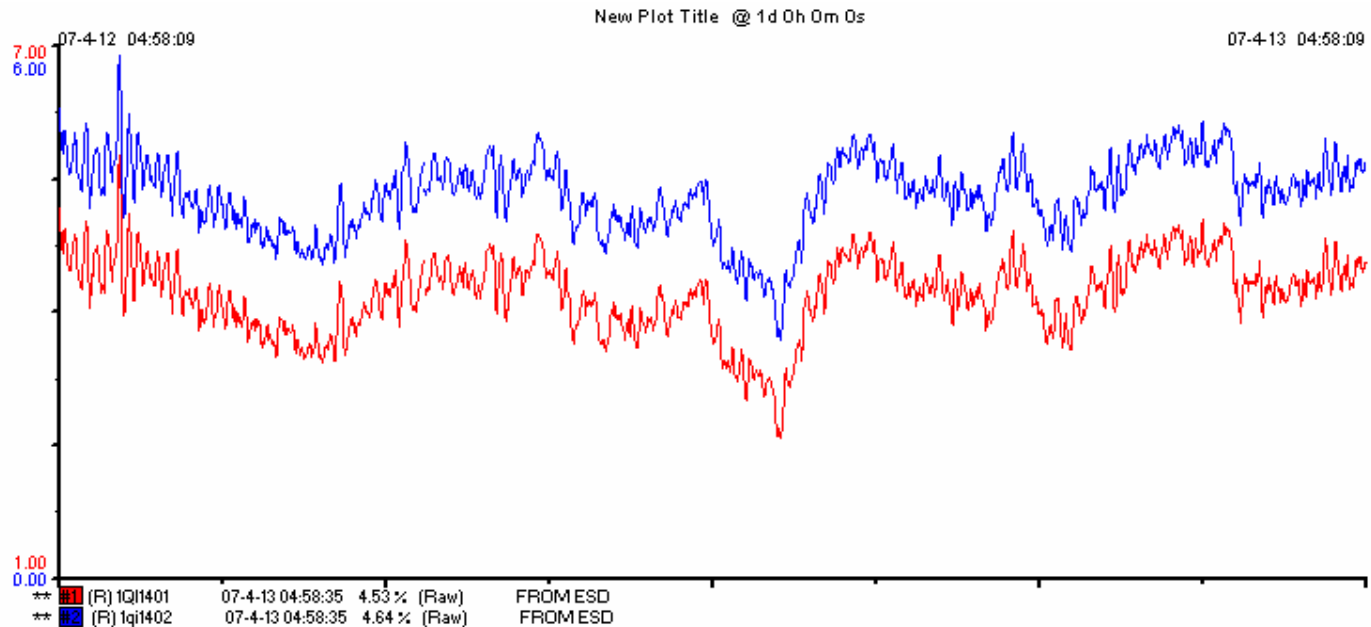




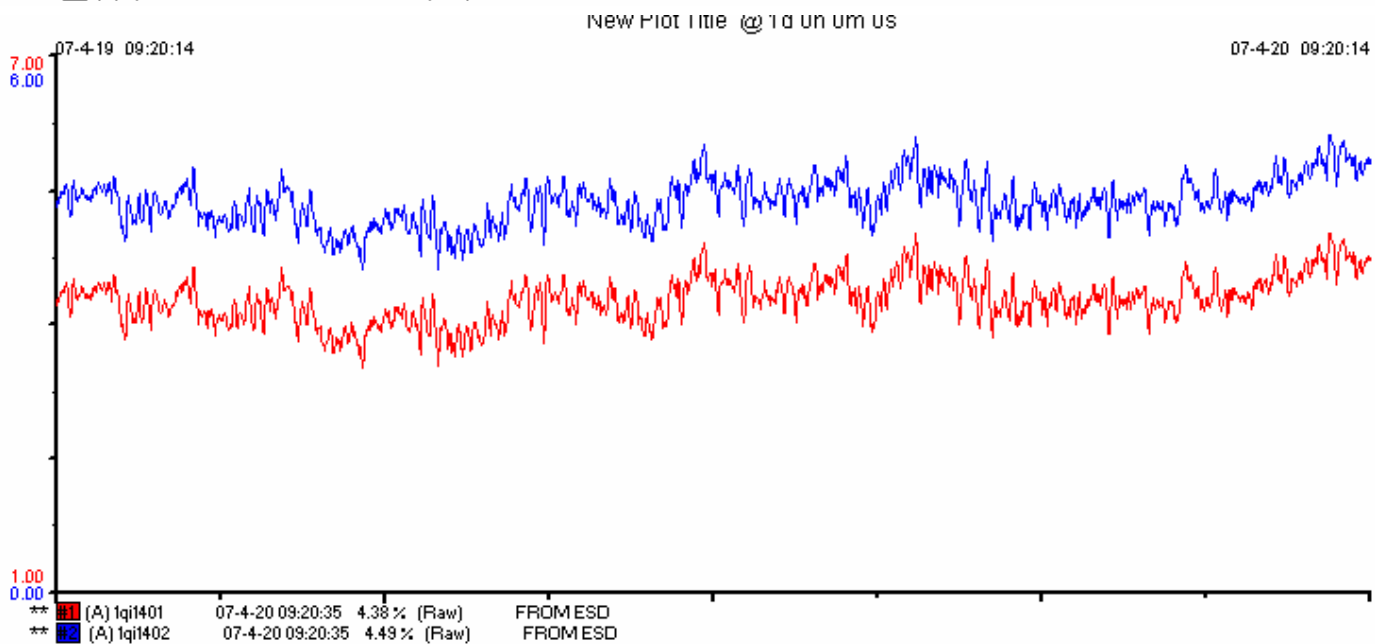
MPC off



MPC on



MPC off



MPC on

5. Future Plans and Outlook

- Add MPC monitor module
- Add Internet access capability
- Our vision:

An MPC controller is designed by a control expert and it can be implemented and maintained by an operator

- An adaptive MPC is justified for **all process units** in the refining/petrochemical industry, not just major units
- An adaptive MPC is justified for **all process industries**, not just the refining/petrochemical industry.