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

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Contents

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.

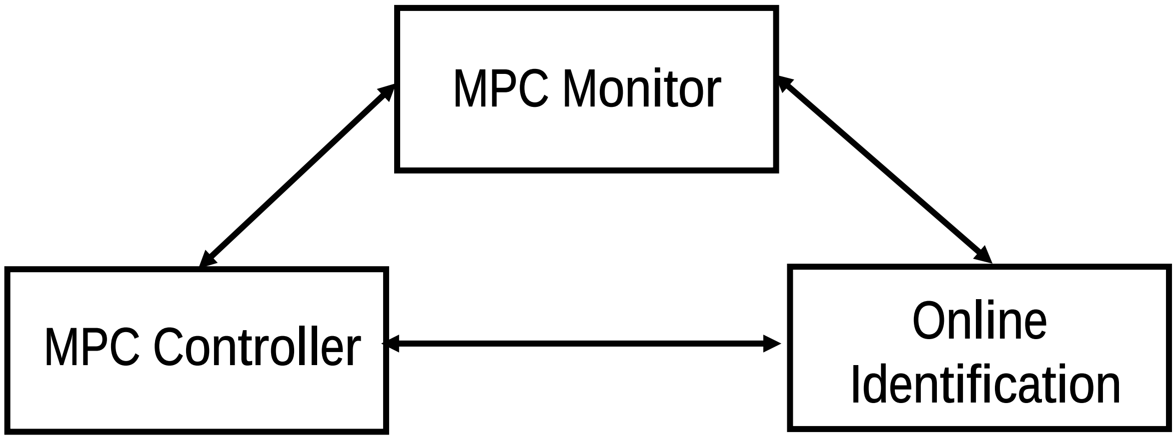
1. Introduction (Cont.)

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.) ?

<u>The Old Way:</u> Series steps, 3 to 4 software packages

Pre-test	**Step test & model ID**	**Simulation**	**Commission**

<u>The "New" ID:</u> Series steps, 3 to 4 software packages

Test & model ID	**Simulation**	**Commission**

<u>The New Way:</u> Parallel procedure, 1 package

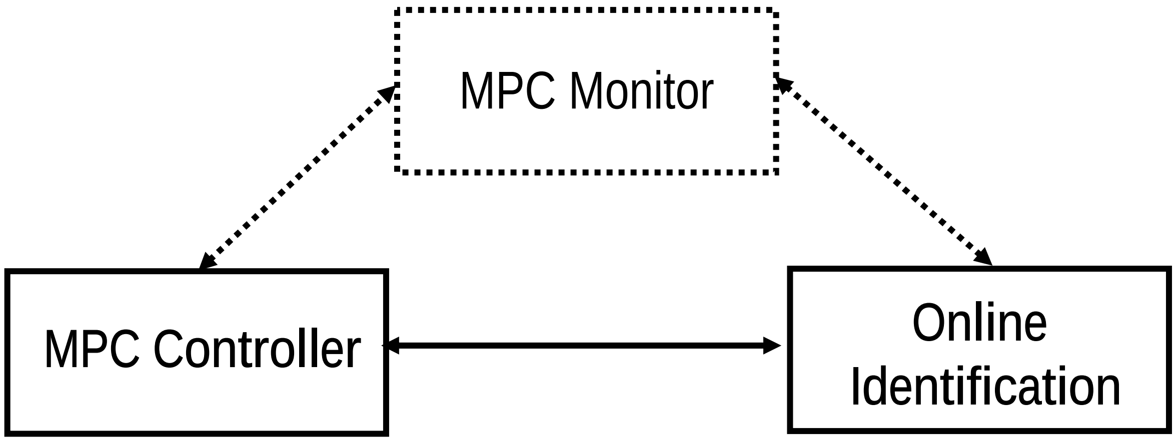
Test & model ID

Simulation

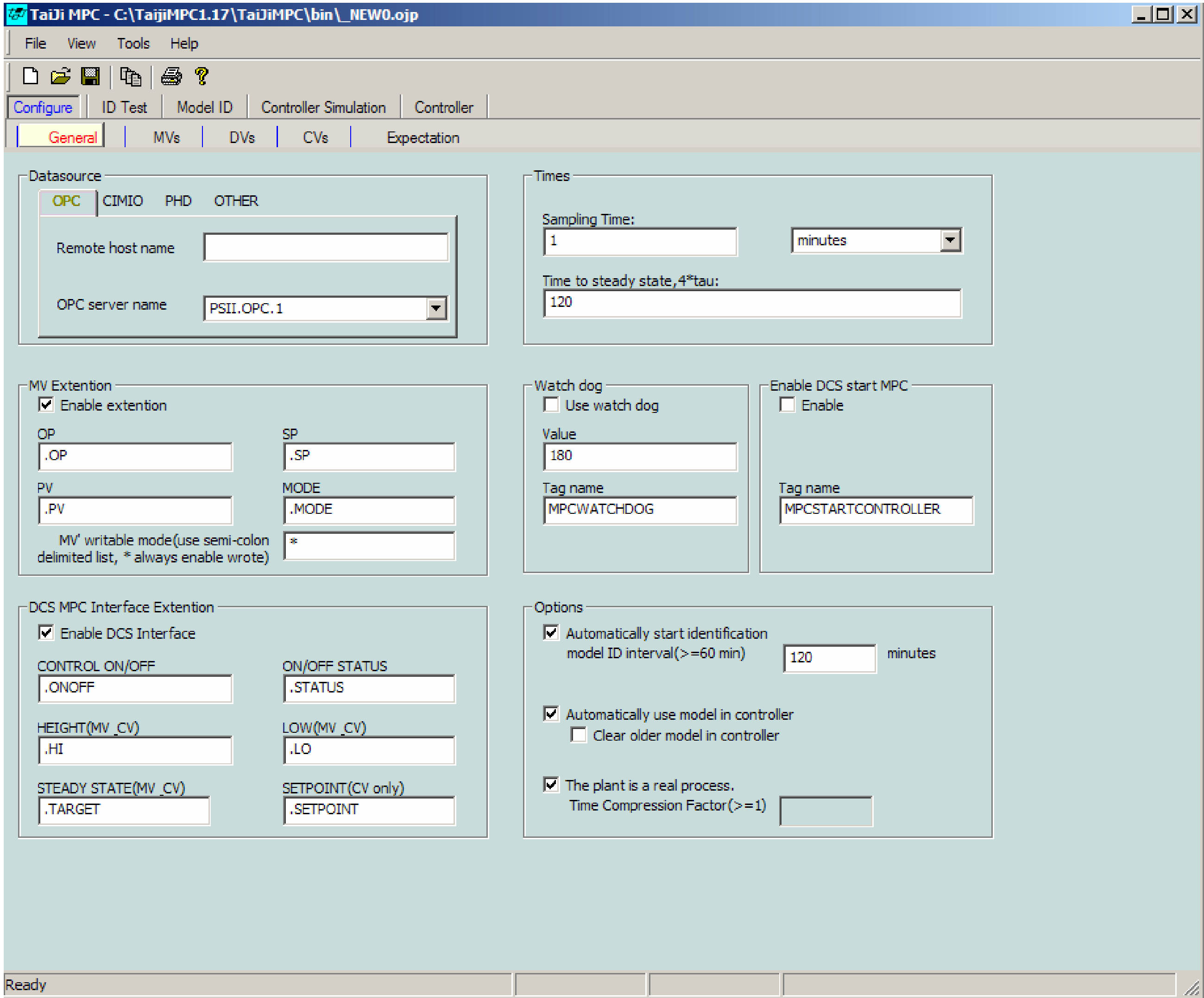
Commission

4. Software Implementation

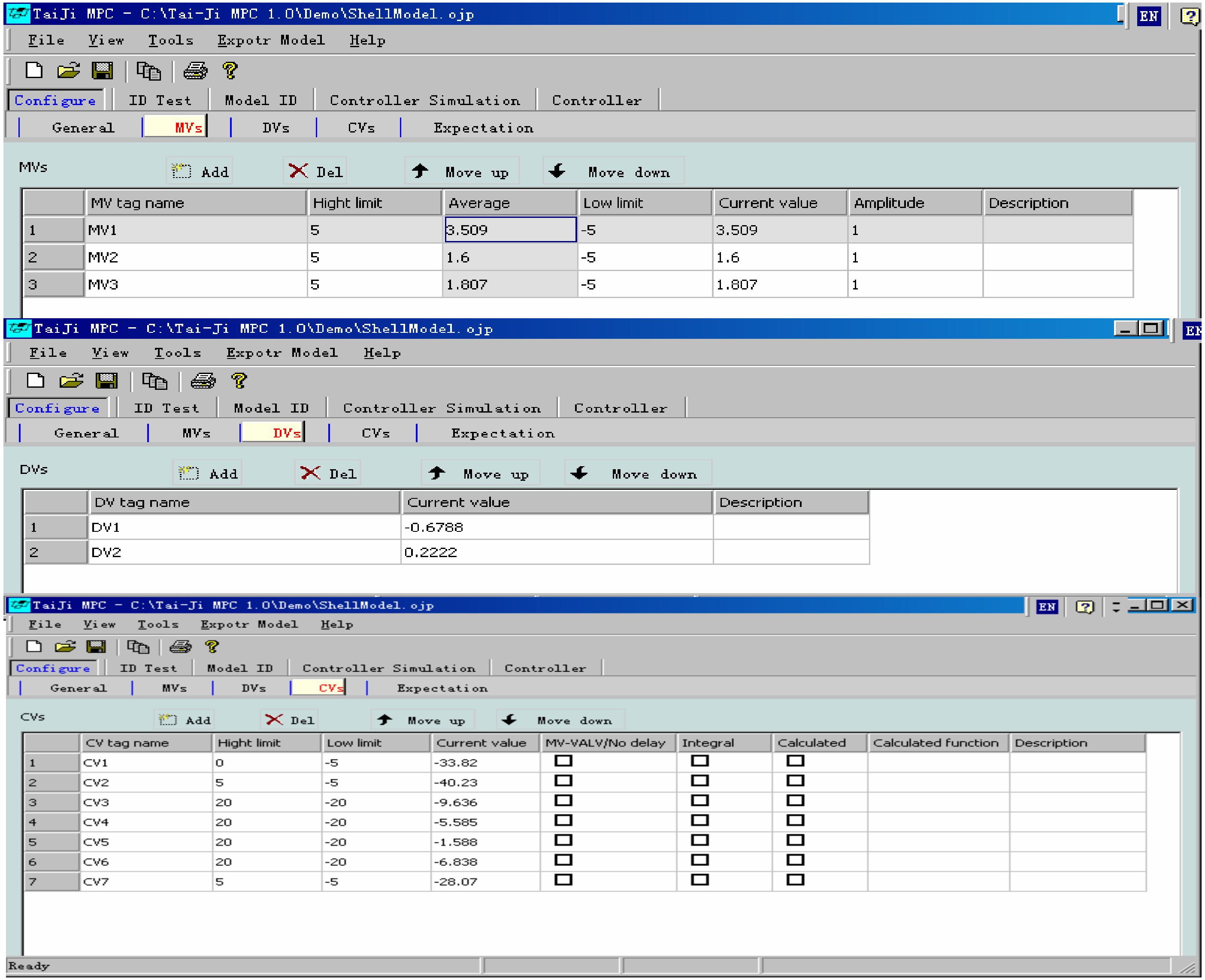
- Two modules are implemented: Controller and Identification
- Can use multi-model and LPV model for nonlinear MPC.



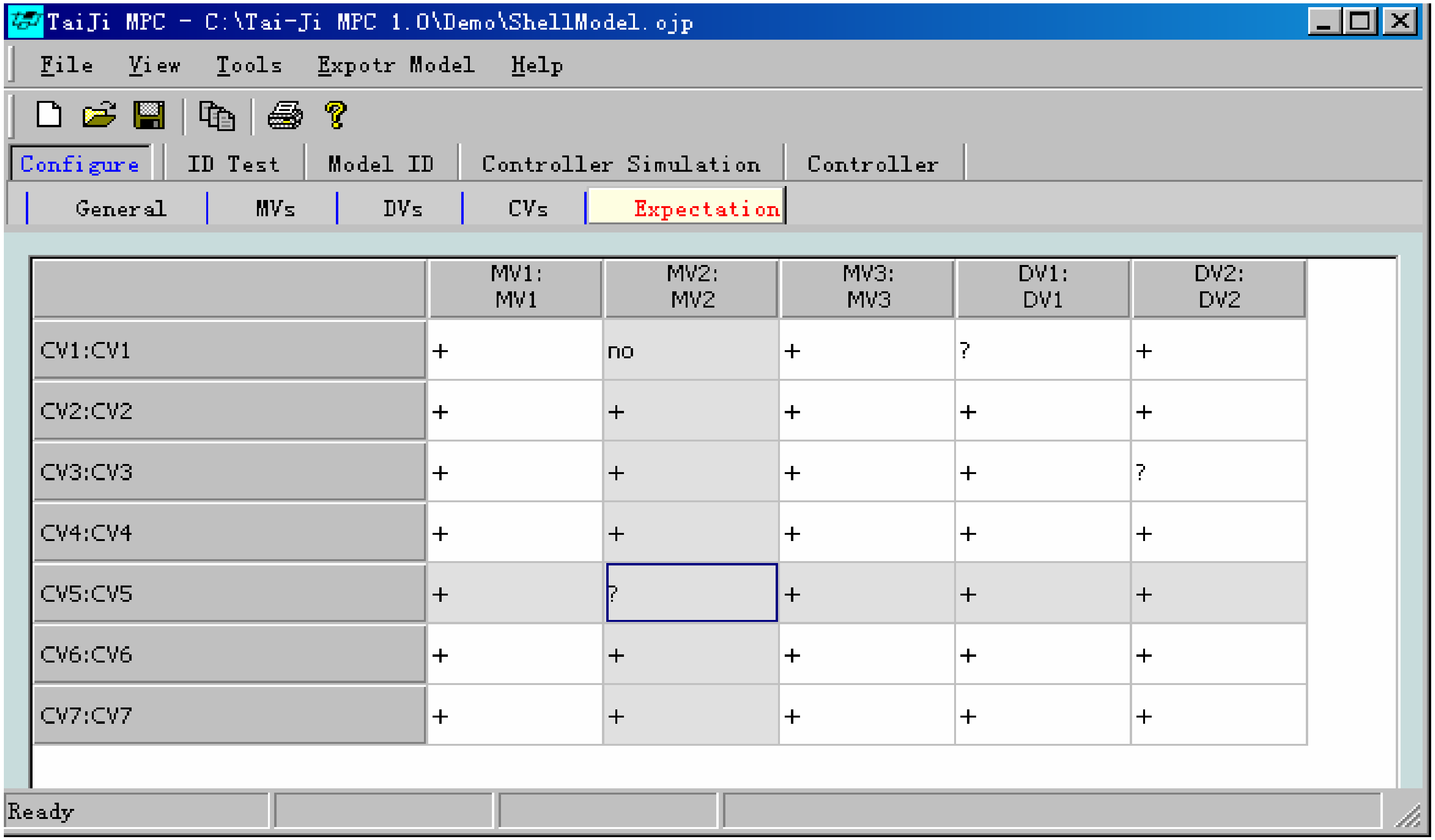
Configuration: Specify general items



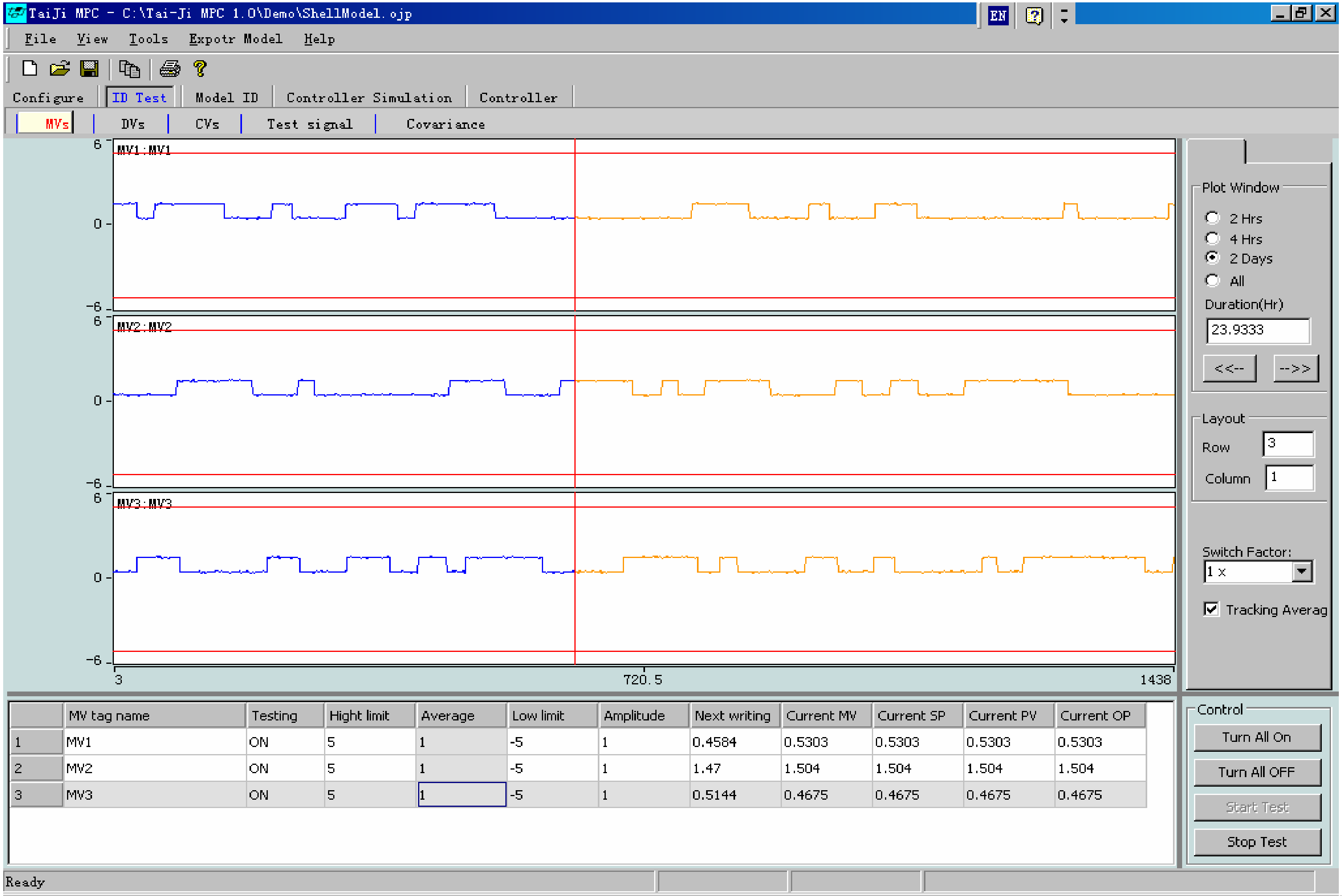
Configuration: Specify MVs, DVs and CVs



Configuration: Specify Expectation Matrix

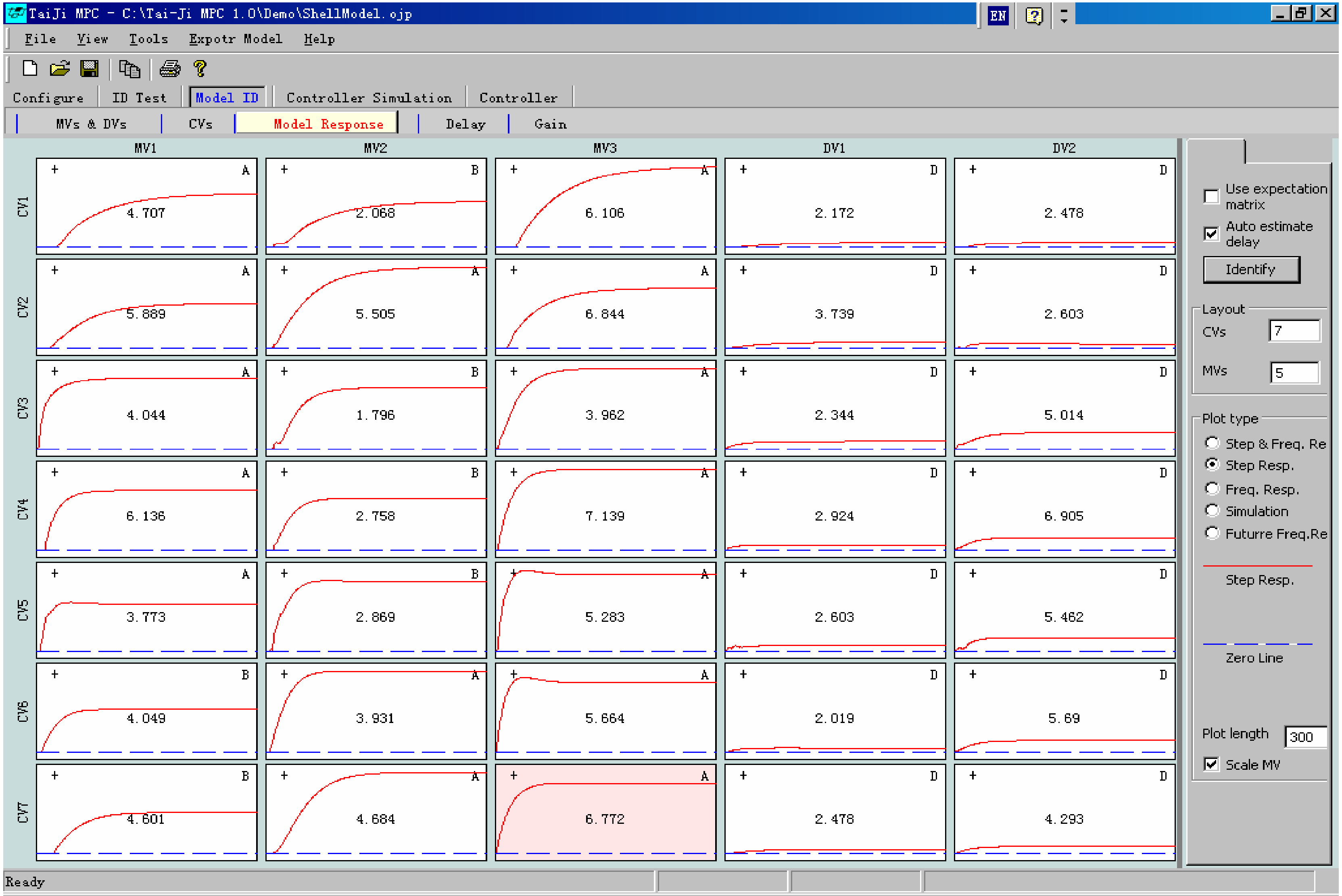


ID Test, MV plots



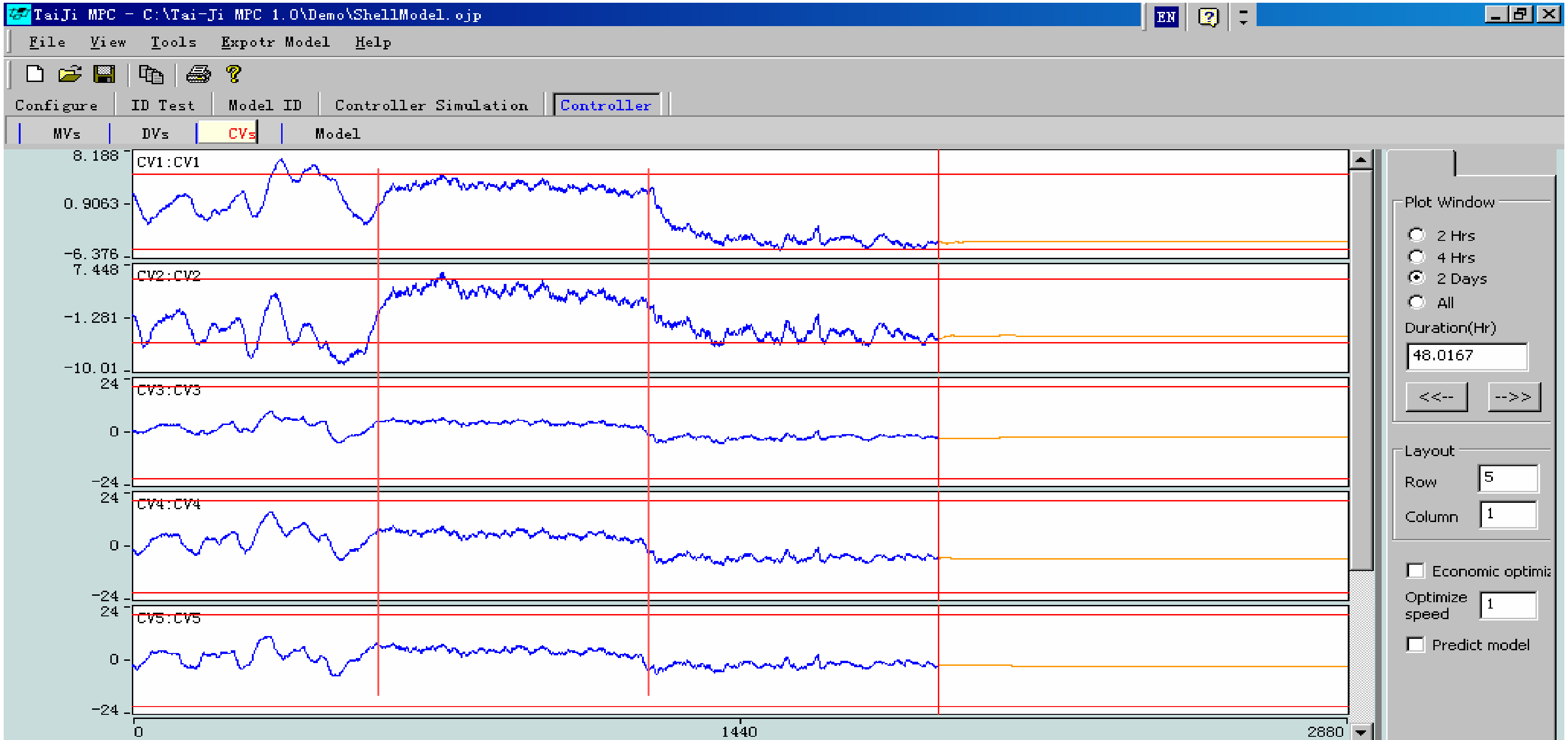
	MV tag name	Testing	Hight limit	Average	Low limit	Amplitude	Next writing	Current MV	Current SP	Current PV	Current OP
1	MV1	ON	5	1	-5	1	0.4584	0.5303	0.5303	0.5303	0.5303
2	MV2	ON	5	1	-5	1	1.47	1.504	1.504	1.504	1.504
3	MV3	ON	5	1	-5	1	0.5144	0.4675	0.4675	0.4675	0.4675

Model step responses



Controlled CVs:

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

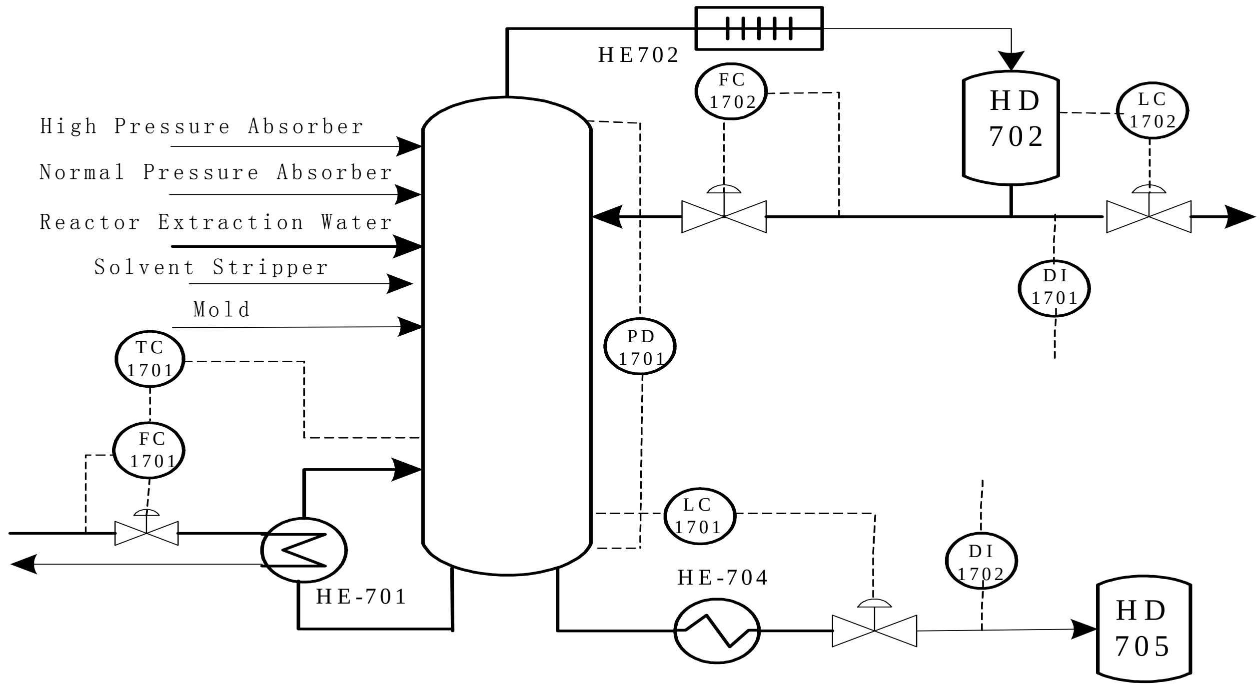


	CV tag name	St…	C…	Cr…	Range type	Setpoint	Hight limit	Low limit	Current value	Steady state	Closed-loop …	Priority
1	CV1	Good	ON	No	Setpoint	-4	5	-5	-4.002	-4	120	1
2	CV2	Good	ON	No	Setpoint	-4	5	-5	-4.569	-4	120	2
3	CV3	Good	ON	No	Range	11	20	-20	-2.417	-1.774	120	2
4	CV4	Good	ON	No	Range	0	20	-20	-5.297	-5.272	120	2

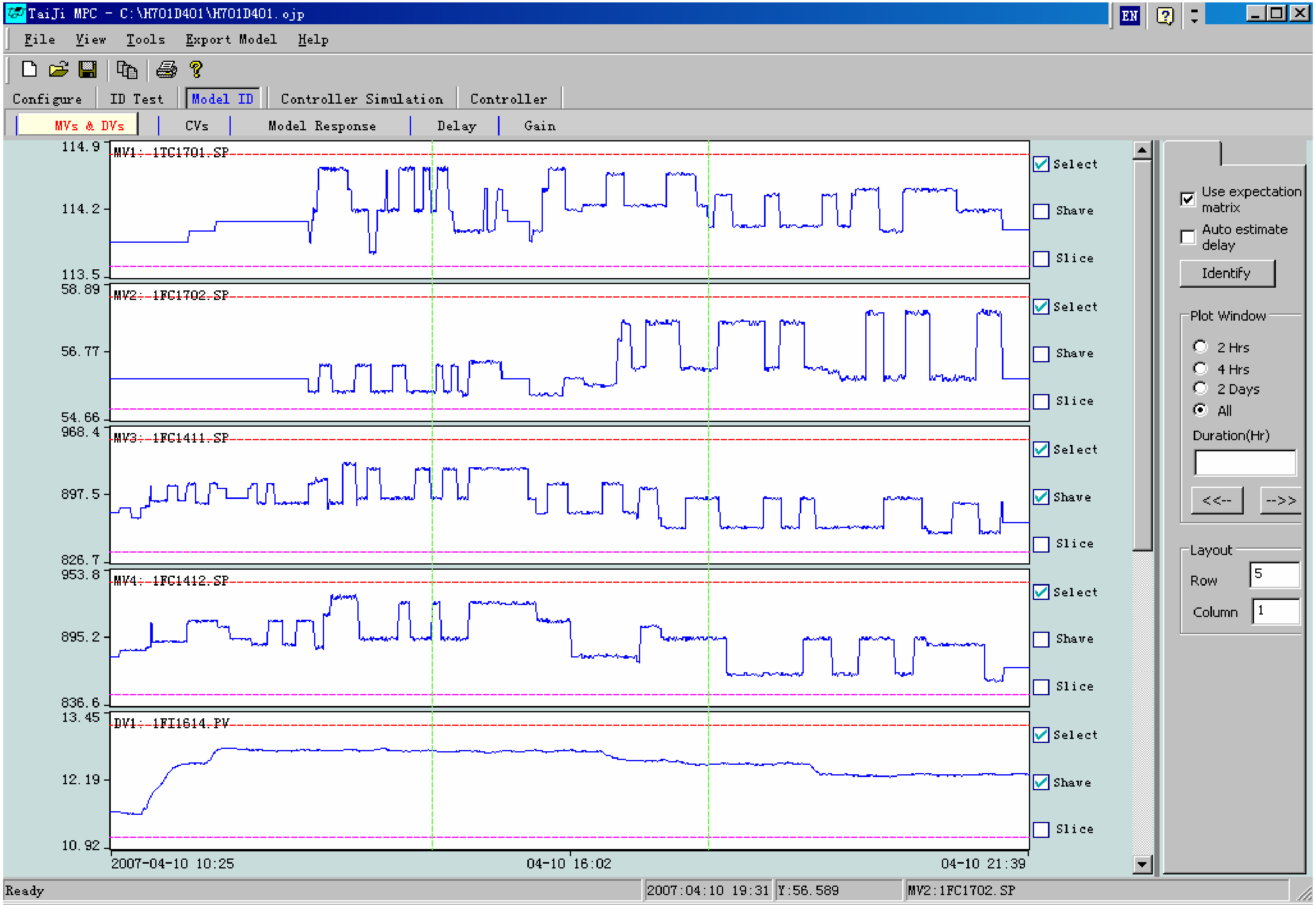
5 Application to a PTA Unit

1) Solvent Dehydration Tower

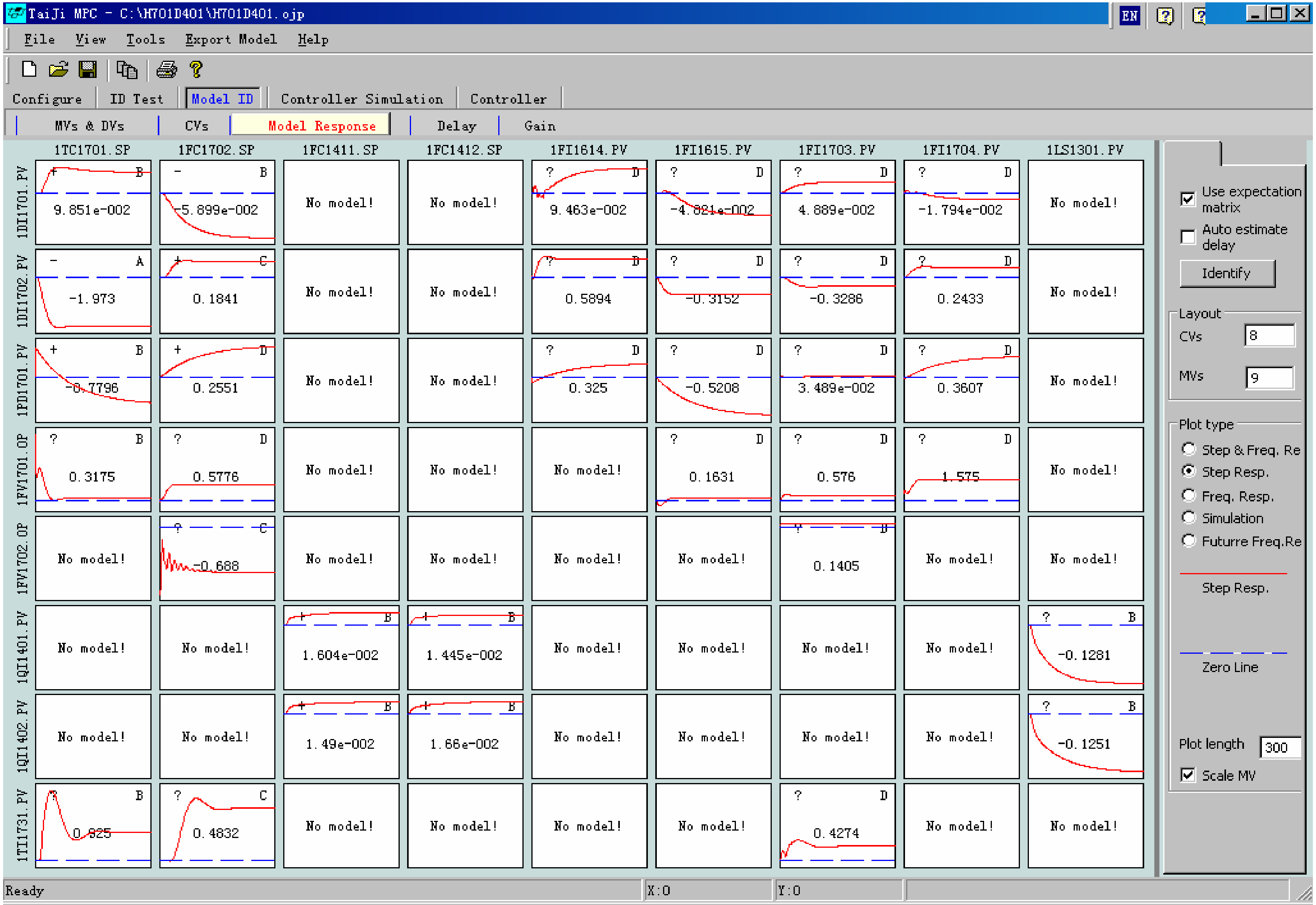
Controller commissioned after 10 hours of test



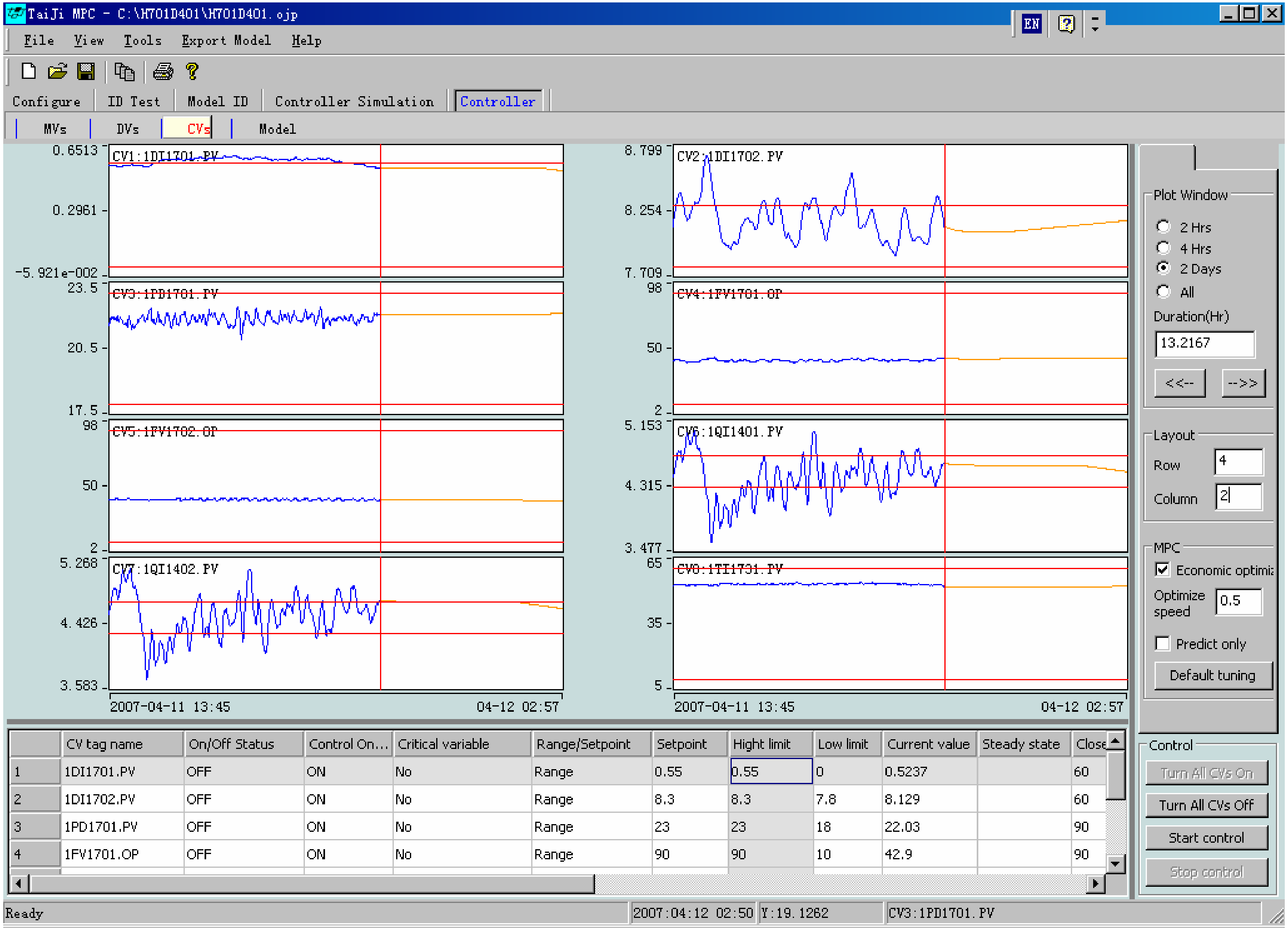
MV Signals during plant test



Model step responses



CV responses after MPC turned on

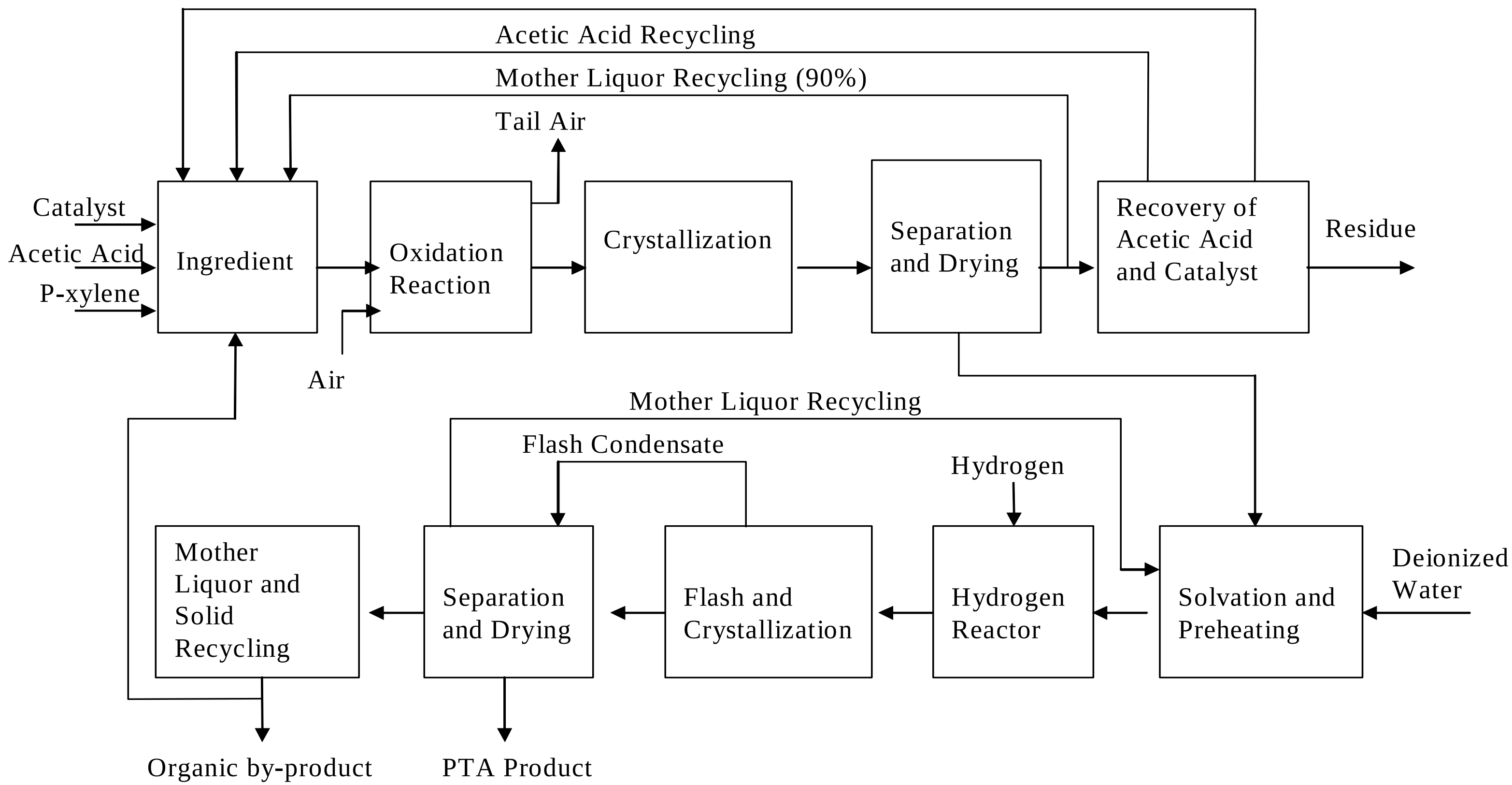


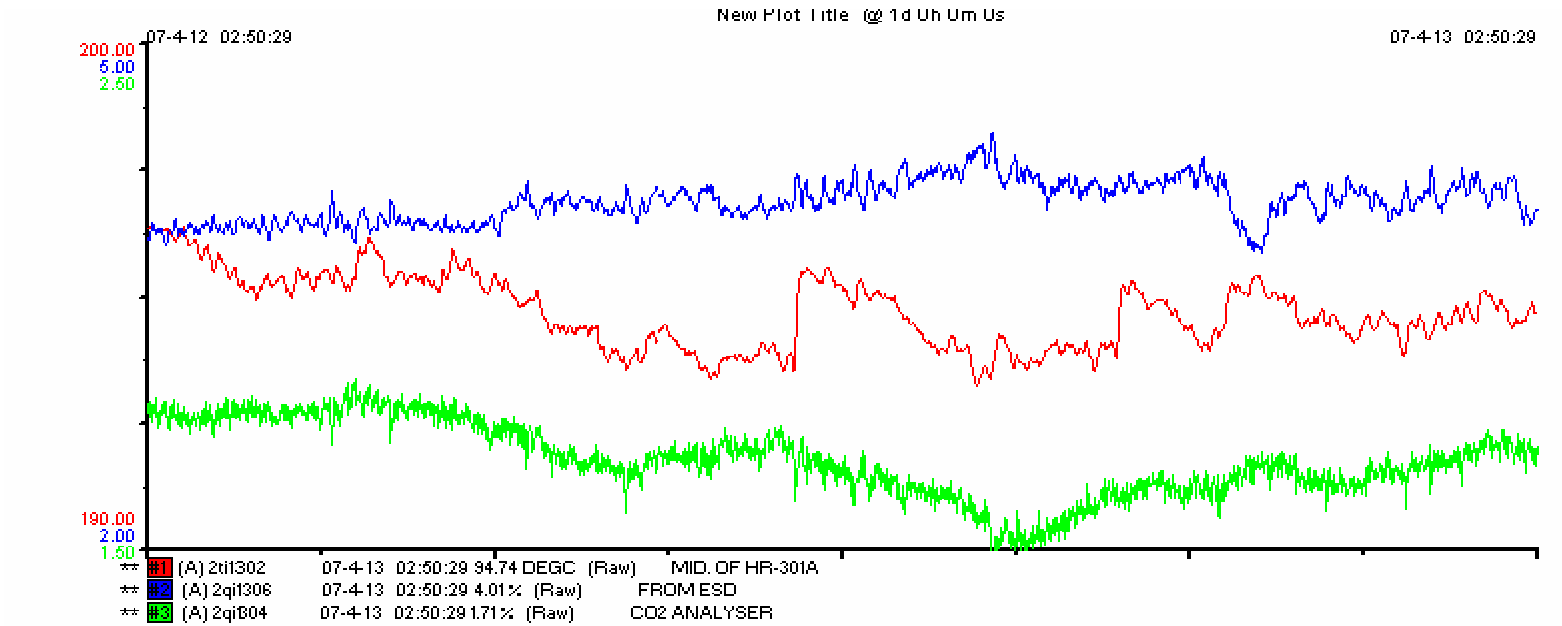
	CV tag name	On/Off Status	Control On...	Critical variable	Range/Setpoint	Setpoint	Hight limit	Low limit	Current value	Steady state	Close
1	1DI1701.PV	OFF	ON	No	Range	0.55	0.55	0	0.5237		60
2	1DI1702.PV	OFF	ON	No	Range	8.3	8.3	7.8	8.129		60
3	1PD1701.PV	OFF	ON	No	Range	23	23	18	22.03		90
4	1FV1701.OP	OFF	ON	No	Range	90	90	10	42.9		90

5 Application to a PTA Unit (Cont.)

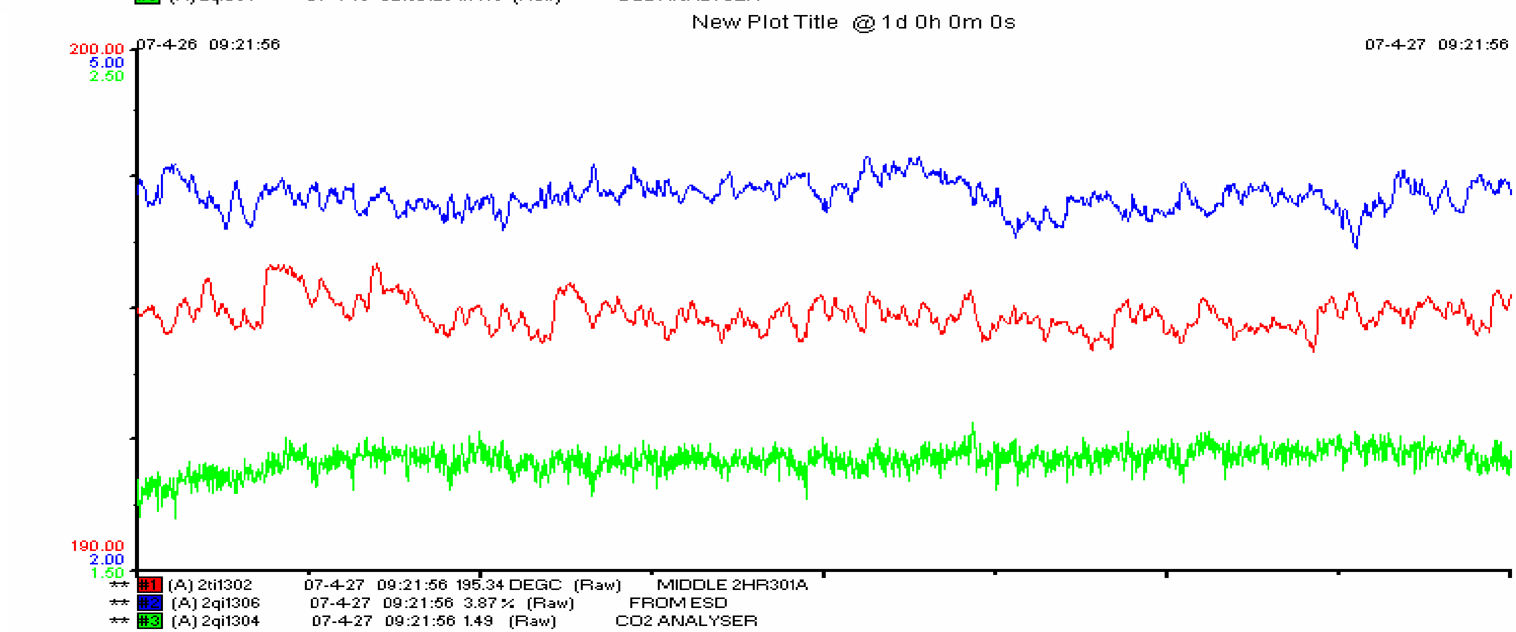
2) Reaction Section

- 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

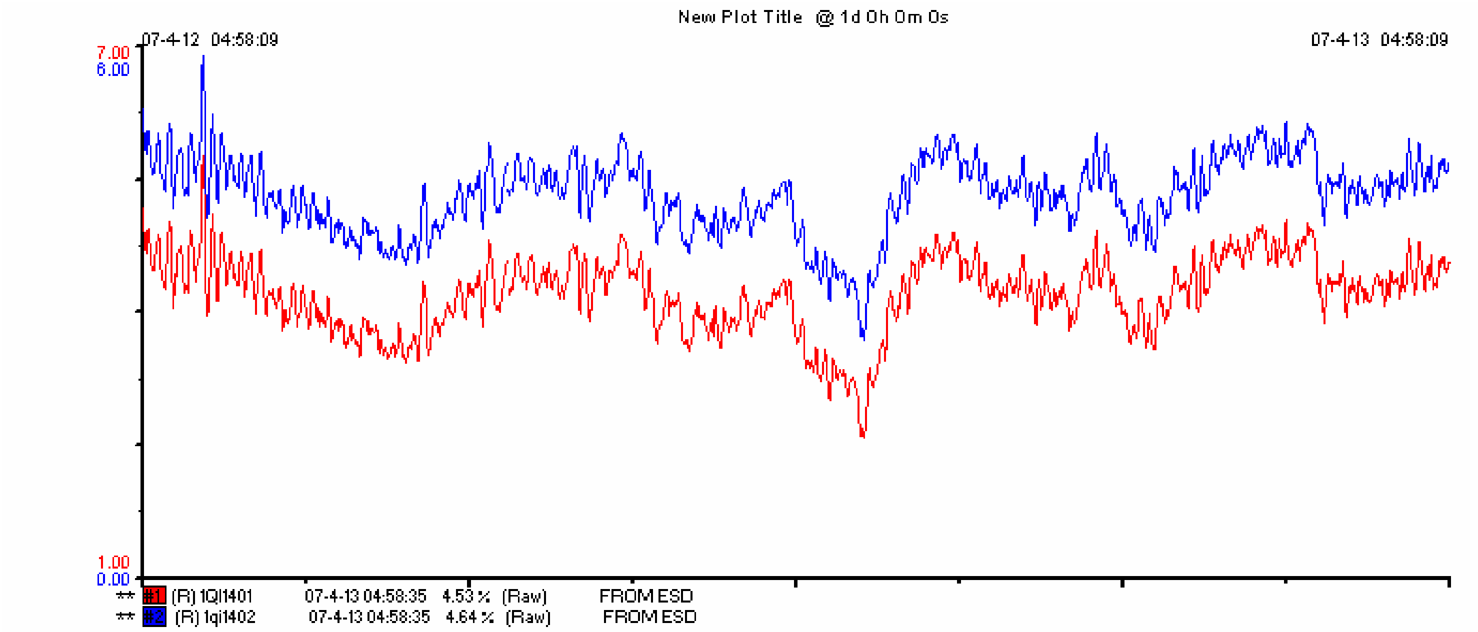




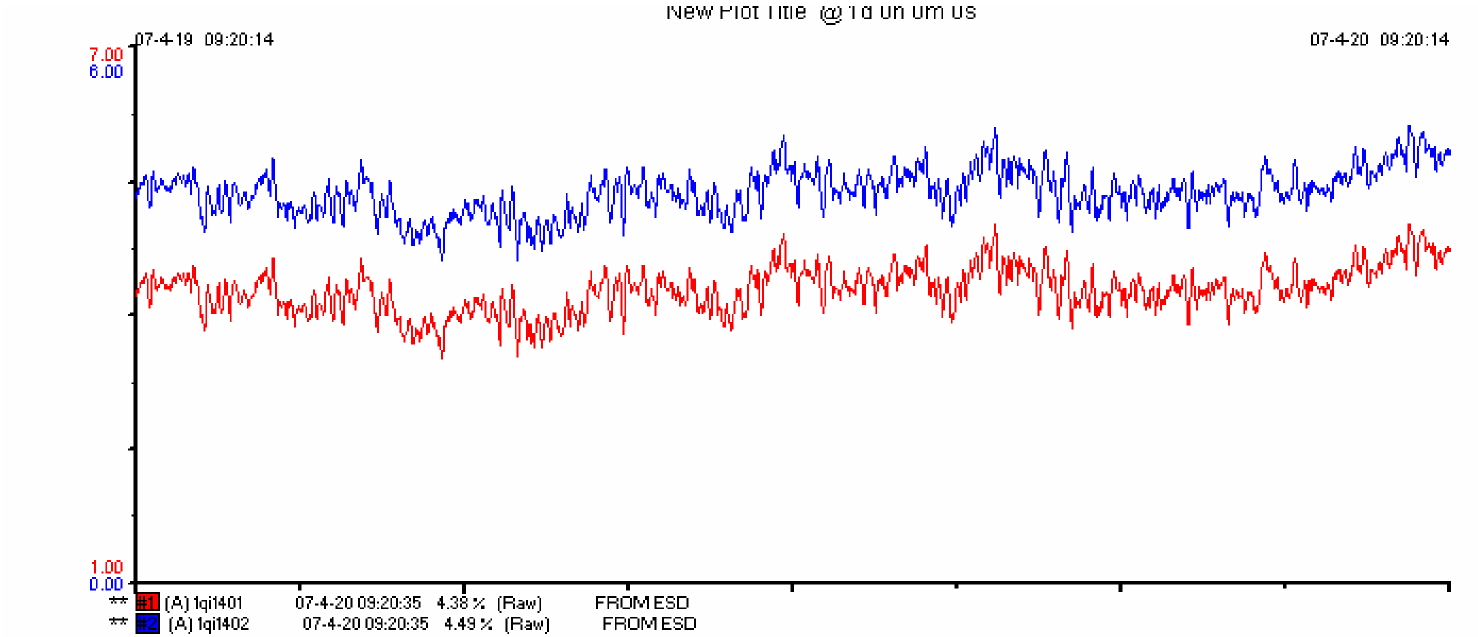
MPC off



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.