How Much Can We Increase the Efficiency of MPC Identification?

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Contents

1. Introduction

- Process identification is the most difficult and most costly part in
  - New MPC projects (40% of project time)
  - MPC maintenance (60% of project time)
- The market demands more efficient MPC identification technologies
- Some major vendors are also responding to the demand
- Tai-Ji ID provides systematic solutions to MPC identification
- Many successful applications have been reported
- Adaptive identification/MPC feasible?

2. Key Issues of MPC Identification

1) Plant Test

- Traditional test method: manual, single variable and open loop
- Modern approach: automatic, multivariable and closed-loop (if possible)
- Advantages of automatic multivariable (closed-loop) test
  - Reduce disturbance to unit operation
  - Shorter test, easy to carry out
  - Better model for control

2) Model Structure and Parameter Estimation

- Traditional method uses nonparametric models, e.g., FIR
- Modern method uses parametric models, e.g., ARX, ARMAX, Box-Jenkins, and state space
- Nonparametric models and some parametric models are not suitable for closed-loop data
- More advanced numerical optimization routines are needed for parametric models
- Model order selection is also a challenging task

3) Model Validation/Selection

- The goal of model validation is to decide if the identified model is suitable for use in the MPC controller
- If not, provide advice for remedies
- Traditional methods use knowledge on process gains and checks on simulation fit
- Traditional methods are *ad hoc* and cannot provide sufficient control-relevant information
- Modern methods use model error bounds that are control relevant
- Modern validation methods can provide advices on adjusting the ongoing test or on test redesign

Misunderstandings about modern identification

1) *Multivariable test will cause too much unit disturbance*

   Correction: Any plant test method must obey the unit operational constraints. Proper step sizes, manual control and closed-loop test can be used to reduce unit disturbance.

2) *The process is not identifiable using closed-loop test data*

   Correction: It is only true with some traditional methods. In general, the process is identifiable using closed-loop data under sufficient excitation (test signals)

3) *MV signals should be uncorrelated*

   Correction: None of the two MV's should be 100% correlated. Good MV correlations can improve model performance in control

3. Tai-Ji ID

1) Tai-Ji ID Test Approach

- Automatic and multivariable plant test
- Signals used normally **GBN (PRBS)**, but can use others as well
- Operator manual control encouraged
- Open loop tests typically moves 10 MVs
- Closed-loop test can use all kinds of existing control (PID, MPC, …)
- Test design examples
  - Crude units, FCCUs or cokers with 20 to 25 MVs, a 5 day test
  - Small columns, e.g., debutanizers and depropanizers, a 30 hour test

2) Parameter estimation

A) Estimate a high order ARX model

B) Frequency weighted model reduction using the maximum likelihood (ML) principle

3) Order selection using ASYC

Minimize the total identification error (in the frequency domain)

4) Model validation

Upper error bound

$$\left|G_{ij}^{o}(e^{i\omega})-\hat{G}_{ij}^{n}(e^{i\omega})\right| \le 3\sqrt{\frac{n}{N}[\Phi^{-1}(\omega)]_{jj}\Phi_{v_i}(\omega)} \quad \text{w.p.99.9\%}$$

Grading the models

A, very good; B, good; C, marginal; D, poor or no model

Ways to adjust the ongoing test

- Modify test signal amplitudes (step sizes)
- Change test time
- Change GBN switch time (signal spectra)

A small history of Tai-Ji ID technology

In the last 5 years, Tai-Ji ID has been applied successfully to over 100 processes in MPC projects. Most tests were done in open loop.

The following are examples of **closed-loop tests**:

1) Partial closed-loop identification of a chemical plant, Germany, 1998
2) Partial closed-loop identification of a debutanizer, Statoil, Norway, 1998
3) Partial closed-loop identification of a deethanizer, Dow Chemical, The Netherlands, 1999
4) Partial closed-loop identification of two distillation columns of a chemical plant, ExxonMobil, USA, 1999
5) Totally Close-Loop Identification of a Vacuum Column, France, 2002

Tai-Ji ID package for Windows 98/2000/NT/XP

1) **Tai-Ji ID 3.2** – Off-line part for computations
   - Test signal design
   - Model identification and validation
   - Model export
2) **Tai-Ji Test 3.1** – On-line plant test program
   - Automatic, multivariable, open and closed-loop plant test
   - Test monitoring and adjustment
   - Data export (to Tai-Ji ID 3.2)

4 Identification of a Chemical Reaction Unit

The Process Unit and the MPC Controller

- A chemical reaction unit
- The MPC has 8 MVs, 2 DVs and 45 CVs
- The MPC controller was commissioned using the traditional step test method
- The initial step test lasted more than 10 days around the clock

Need for alternative identification methods

- Traditional test is open loop, single variable and manual
- Test time is very long and the work load is high
- The operator is requested to move one MV at a time and not to change other MVs as far as possible
- Data analysis and modelling is time consuming (few days to few weeks)
- Model validation/selection is difficult, relies on in-depth process knowledge and many reviews with operations

Initial concerns about automated and multivariable test method

- Moving all MVs and DVs may need greater attention to monitor the test
- Multivariable and correlated moves may lead to poor model quality
- Model gains may be poor because there are many fast MV moves
- Moving all MVs and DVs randomly may disturb the unit too much and pose operational concerns

Tai-Ji ID test and identification

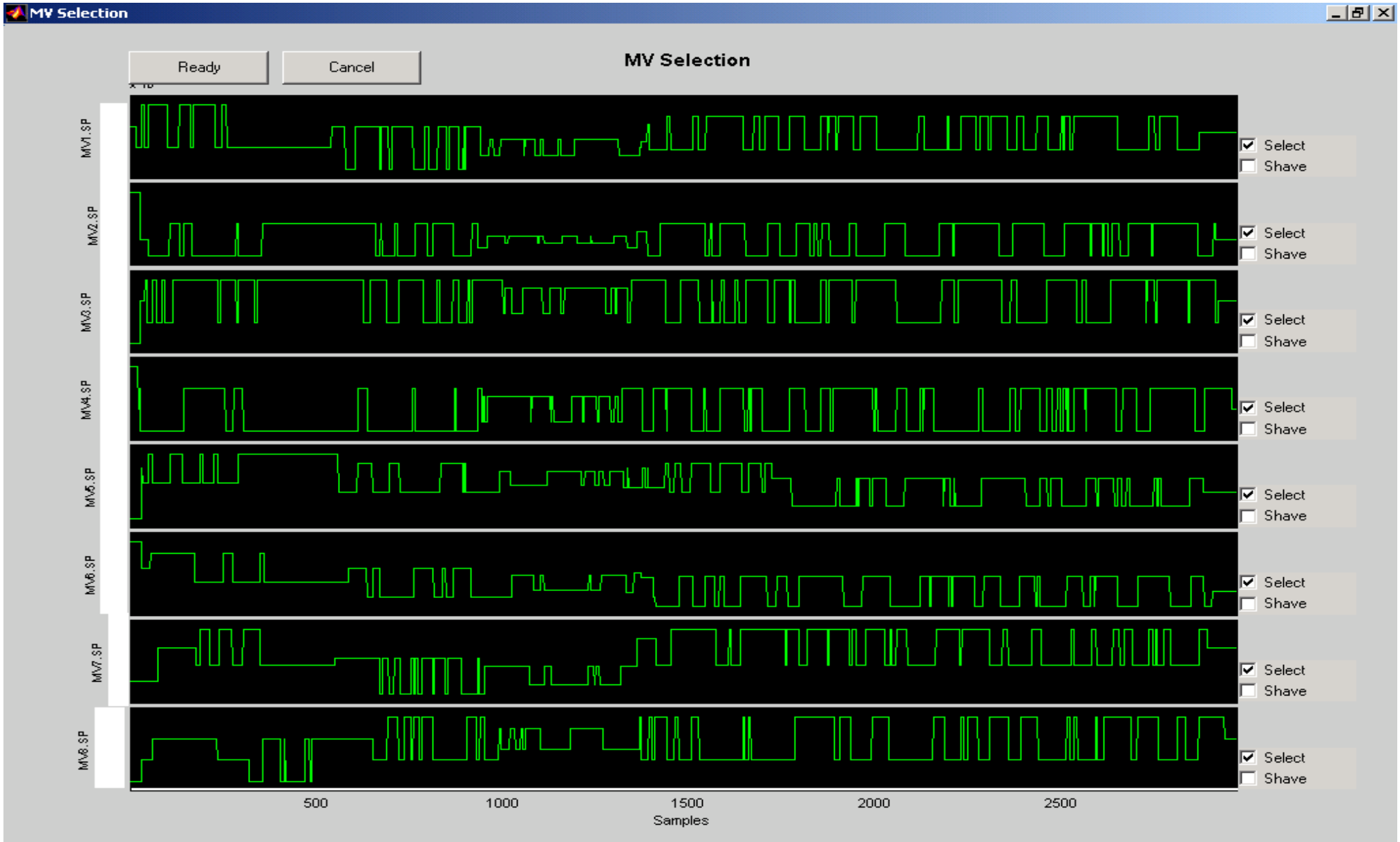
- All the 8 MVs were moved by Tai-Ji Test using the designed test signals
- MV step sizes were chosen according process knowledge
- Intermediate model identification was carried out during the test, MV step sizes were adjusted based on model validation
- The test did not affect unit operation
- The test was stopped at 60 hours, after most of the expected models were identified with A (very good) and B (good) grades
- Model identification took several hours

Advantages of Tai-Ji ID Technology

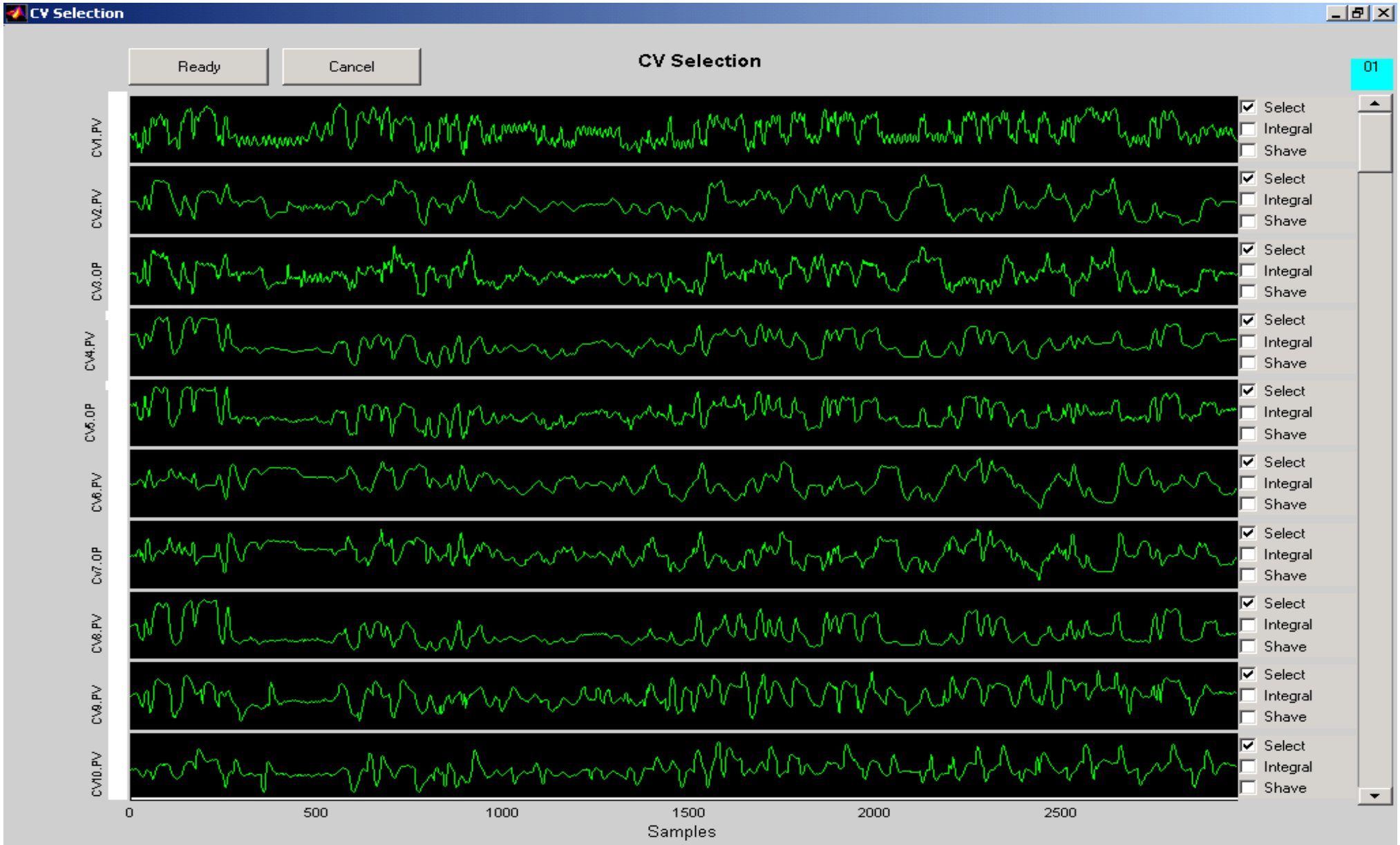
- **Fast and easy test.** The APC engineer coverage is minimal to moderate, not around the clock; short test is easy to plan and complete, attractive to operations
- **Easy model development.** Tai-Ji ID model identification procedure is easy and straightforward. Model development takes a few hours in stead of a few days. Model grading can be used to adjust the ongoing test
- **Better way to model validation/selection.** The upper error bounds and model grading enable the APC engineer to validate and select models in a an easy and sound manner

Advantages of Tai-Ji ID Technology (Cont.)

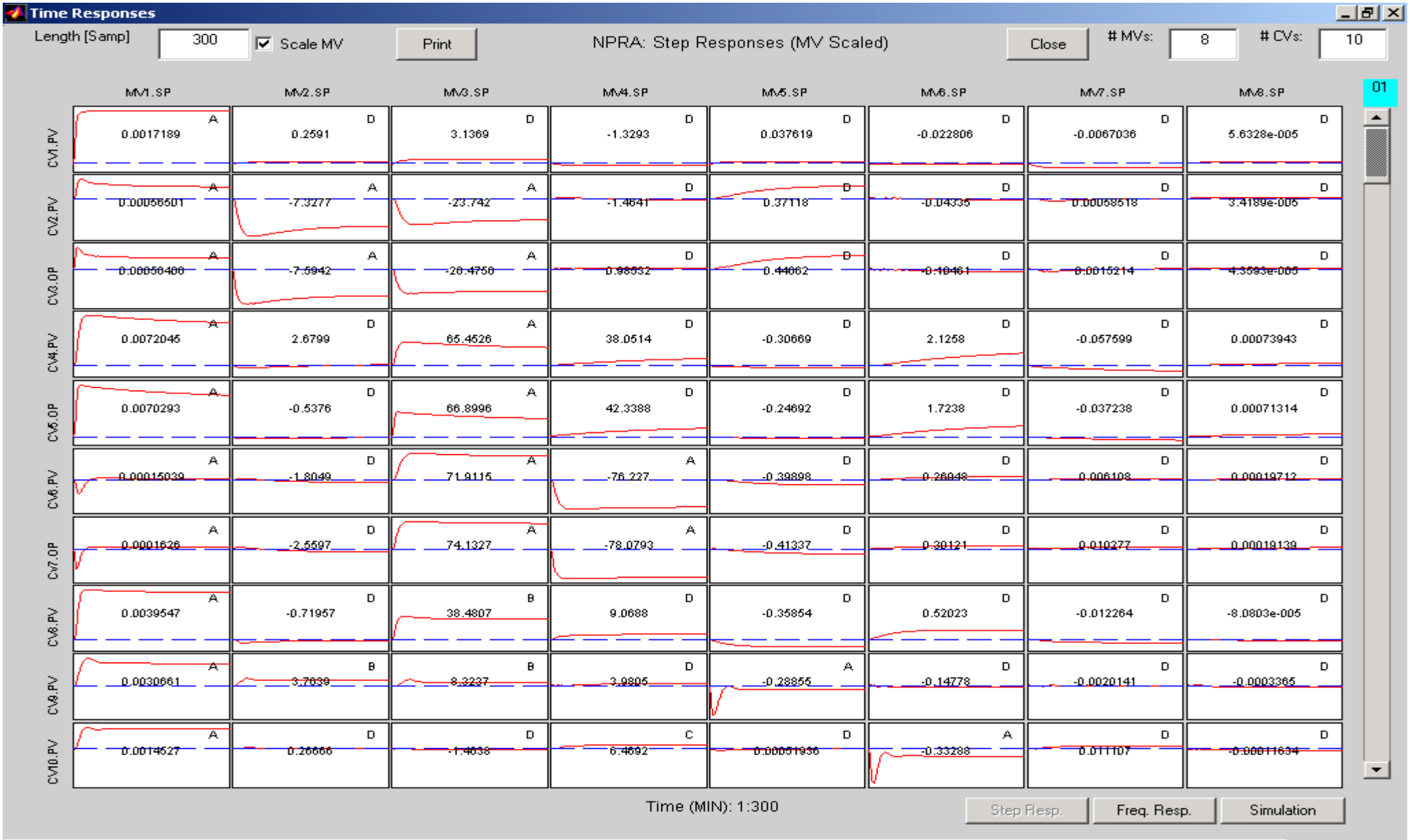
- **Better models.** This is manifested in the significant reduction in the use of APC engineer assumptions/intuitions
- **More new models.** Tai-Ji ID provides more models than existing ones, that gives more in depth process understanding. Moreover, these new models can improve the MPC performance
- **Low cost and efficient solution.** Tai-Ji ID saves 80% plant test time, several weeks of APC engineer time for the model development and quite a few model review sessions with the operations.
- **Keeping up the MPC controller uptime and benefits.** Tai-Ji ID can be used whenever needed without haggling over the justification needs. On time maintenance will keep up the MPC controller uptime and benefits



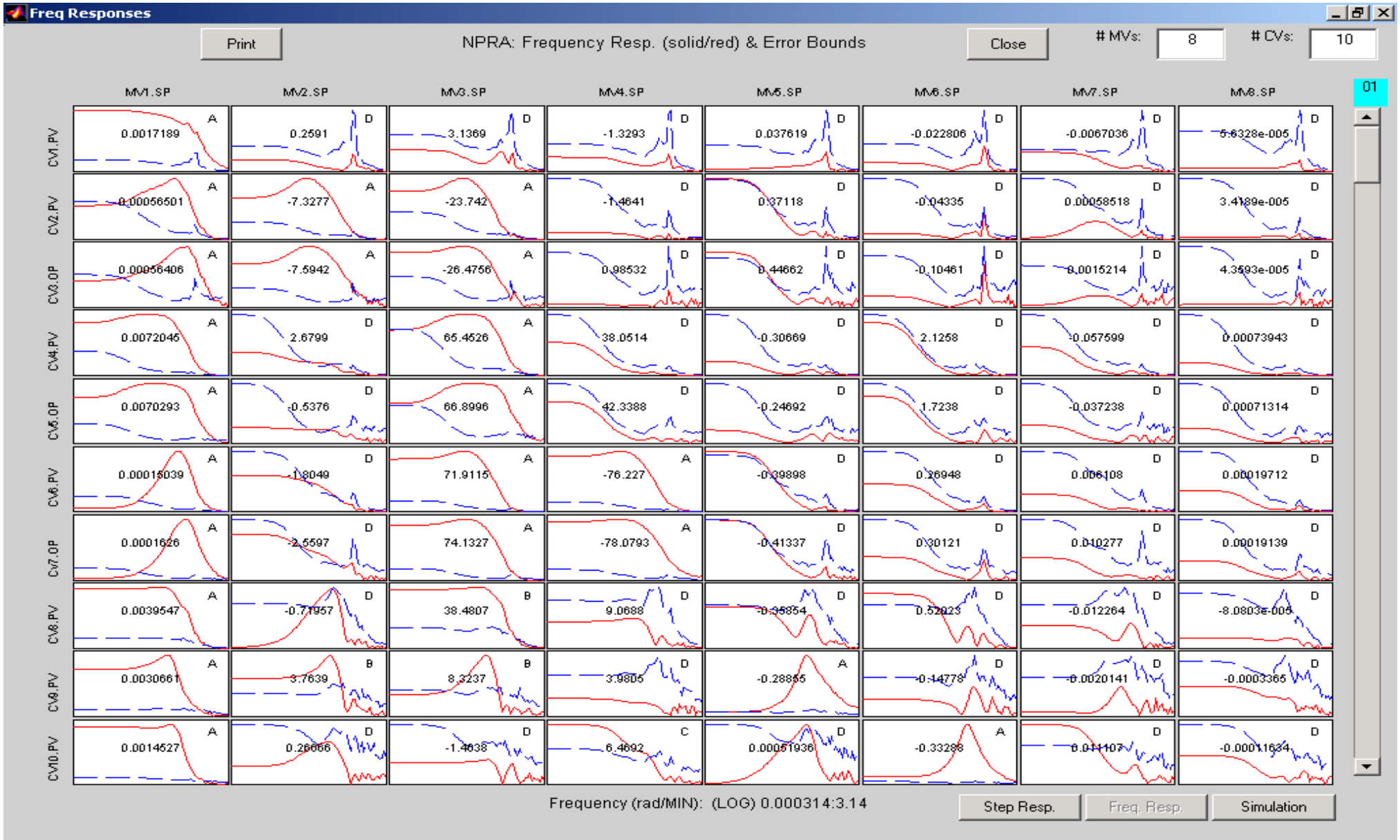
MVs movements during the ID test



Part of the CVs during the ID test



Step responses of identified models



Frequency responses and upper bounds

5. Conclusions and Perspectives

1) The MPC market demands more efficient identification technologies
2) Tai-Ji ID provides systematic solutions to MPC identification
3) Some traditional misunderstandings need to be corrected
4) The advantages of Tai-Ji ID
    - Save 70% test time
    - More accurate model for control
    - Save 80% data analysis time
    - User friendly
5) Adaptive identification/MPC is possible!