Closed-Loop Identification at the Hovensa Refinery

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Abstract. The Hovensa refinery located in the US Virgin Islands is a joint venture between a subsidiary of Amerada Hess and a subsidiary of Petroleos de Venezuela, S.A. (PDVSA). The facility is one of the most modern refineries in the United States and, with crude oil processing capacity of 495,000 barrels per day (BPD), is one of the largest in the world. The latest round of MPC retesting at the refinery was completed in an automated fashion, stepping multiple independent variables simultaneously while the MPC controller was in service**.** The crude #6 MPC application has 34 MVs and 90 CVs covering two furnaces, an atmospheric tower and a naphtha stabilizer. During the plant test, an existing MPC controller is online and active in stabilizing the operation while the test program moved all the 33 MVs simultaneously. The duration of the closed-loop plant-test, model identification and review was only eight days. The plant test was found to be non-intrusive to the normal operation of the plant allowing the operators to concentrate on their normal duties. This paper describes the technology, its use on a large MPC application on the crude #6 unit and documents the results of the testing and modelling project.

1. Introduction

In the last two decades, MPC technology has created tremendous value for the refining and petrochemical industries. An MPC controller can push the process unit to a more profitable region without violating operation constraints. It is not unusual that a large unit MPC generates one to two million US dollar benefit per year. Refineries and petrochemical plants worldwide have implemented MPC controllers for their major processing units. However, huge benefits come with a high price. To implement and to maintain MPC controllers need highly trained and experienced control engineers; MPC projects are very time consuming. Maintenance is becoming a main issue in MPC applications. Due to the lack of maintenance, many MPC controllers are not fully utilized.

Although the development of new projects remains moderate, there is a move from project work towards maintenance of existing MPC applications to sustain given benefits. As the number of installed MPC applications increase with limited process control engineering resources, the use of improved technology tools help offset the required time investment to maintain existing applications and implement new applications.

Running process units at their most optimum economical condition while adhering to process limits and safety considerations should be the goal of all refineries worldwide. That is the goal at Hovensa. Toward that goal, Hovensa initiated a project to upgrade the MPC control models on Crude Unit #6. This presentation will outline and describe in detail the steps taken and the advantages gained.

The Hovensa Refinery

The Hovensa refinery located in the US Virgin Islands is a joint venture between a subsidiary of Amerada Hess and a subsidiary of Petroleos de Venezuela, S.A. (PDVSA). Hovensa, L.L.C. became the owner and operator of the St. Croix oil refinery on October 30, 1998, which was previously owned and operated by Hess Oil Virgin Islands Corp. (HOVIC). PDVSA, V.I., Inc., a Virgin Islands subsidiary of PDVSA purchased fifty percent of the assets of HOVIC. HOVIC and PDVSA, V.I., Inc., assigned their perspective interests to the joint venture company, HOVENSA, L.L.C, which the two companies previously organized under the laws of the US Virgin Islands.

In the 1960’s when the oil refinery was original built by HOVIC in coordination with the Virgin Islands Government to help diversify the economy of the islands, the refinery had a capacity of 45,000 barrels per day. Today, the facility is one of the most modern refineries in the United States and, with crude oil processing capacity of 495,000 barrels per day (BPD), is one of the largest refineries in the world.

Crude Unit Number 6

The number 6 crude unit, 6CDU, Figure 1.1, is capable of processing 190,000 barrel per day (BPD) of raw crude. Crude is preheated with heat exchange from product heat exchangers before being heated in two parallel four pass heaters. Heated feed enters the 6CDU in the flashzone, where it is distilled into seven products plus resid.

6CDU has had MPC control since 1998.The 6CDU MPC application has 33 MV’s and 94 CV’s covering two furnaces, an atmospheric tower and a naphtha stabilizer. As with any process unit, as run time increases, process problems develop, valves fail, heat exchangers foul, heater preheat systems fail, huge upsets can cause possible tray damage, process instruments fail, process conditions change, crude types being processed change, etc.. All of these things can make the original process models used in the MPC controller, less accurate than they were originally. The unit operating and processing conditions when the models were first developed just isn’t the same as unit run lengths increase. So what can be done? The answer to this question may be to re-model the unit to develop new process models for MPC to regain optimal performance. However, the cost of doing so must be weighed against the benefits gained.

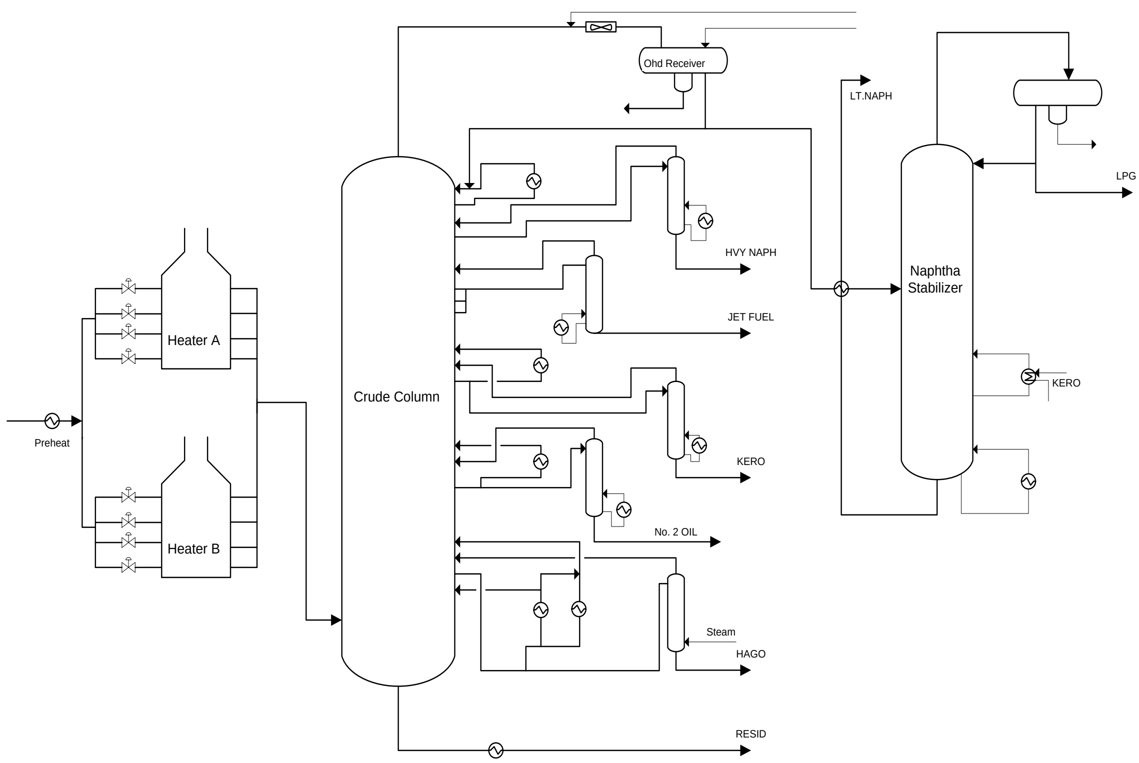

Figure 1.1 - No. 6 Crude Unit

Model Upgrade

6CDU is running late in its current run cycle and will need to be turned around sometime over the next year(s). The problem is that MPC remodeling projects can be very time consuming, intrusive to process operations by stepping process variables for weeks on end, and can be very expensive and involves:

- Manually inspecting all regulatory controllers for proper controller tuning and valve operation. Thus requiring the retuning of controllers and/or fixing/cleaning/replacing valves and or instruments.

- Notify the Planning department of upcoming step-tests and request they plan for a more steady diet of crude slate to avoid unnecessary upsets.
- Notify Operations personnel of upcoming step tests so they have appropriate and adequate staff on hand to help with any process problems that develop.
- Perform the step test one variable at a time. This is very time consuming. Each variable must be stepped and held until steady state is achieved, sometimes up to two hours per variable. Each variable is then stepped multiple times. Step testing 33 MV's is a very time consuming proposition requiring up to four weeks of step testing, seven days a week, 24 hours a day.
- After step testing is complete, model identification begins. Model identification can take another two to four weeks.
- However, if during the modeling identification, some models are not adequate, than additional step tests must be performed, followed by more modeling identification.

This leads to questions that must be answered before proceeding with an MPC model upgrade project.

- Are the old models so bad that they must be replaced?

- Or to turn that same question around, would obtaining and using the new models justify the costs associated with a project to run new step tests and perform new model identifications?

- What if the models are not that bad, but are recognized to not be as accurate as they once were earlier in the unit run life?

- Can the product losses be justified by continuing to use the old models even though product qualities are no longer being pushed as closely to their limits as they once where?

Oddly enough, even with some product giveaway on the unit due to less accurate models, the costs of a MPC controller model upgrade project perhaps still can not be justified. That is, unless the costs associated with the project could be reduced by doing the project more efficiently with less time investment. This is the decision made at Hovensa; to do the 6CDU step test and model identification in a timely and efficient manner translating into a substantial cost reduction. This paper explains how it was done.

The Technology Used
The problem breaks down into two primary pieces as implemented at Hovensa.

- Maintenance and detection of problem regulatory controllers
- Step testing MPC control variables and model identification.

The solution is in the technology chosen to perform these tasks. The choices made at Hovensa are:

- Process Doctor for control loop pre-test analysis
- Tai-Ji Online or ProcessDoctor—Tai-Ji for online step testing and model identification

2. Process Doctor

During a typically pre-test, a minimum of one week is scheduled in order to evaluate the health of the regulatory controls and identify controllers requiring tuning or more involved repair. If major regulatory controller repair work is identified, it has the potential to delay the plant-test by weeks.

ProcessDoctor is a monitoring and diagnose tool for regulatory control loops that provides the platform to troubleshoot under-performing loops efficiently thus maintaining a high performance control system by identifying loop performance problems before controller issues become major problems. .

It automatically generates reports on a regular basis comparing controller performance to benchmarked industry standards. These reports are used to identify and prioritize controllers not performing to industry standards. Additional tools allow for the analysis of these poor performing controllers to identify whether the problem is due to valve problems, tuning, disturbances, oscillations, etc. Having the problem identified allows for a solution to be implemented. The solution may be as simple as tuning the controller, to cleaning the valve stems, to replacing the valve. Regardless of the means by which the poor performing controller has been fixed, the software provides for the early automatic identification of potential problems with regulatory controllers so that most problems can be remedied before a major repair or process upset results. Essentially, the ProcessDoctor tool can be used to sustain regulatory control loop performance proactively thus considerably minimizing MPC pre-test activities

Using this software, Hovensa monitored the daily reports generated prior to 6CDU step-testing as part of normal daily routine work to identify problem controllers. In most cases, controllers simply needed to be tuned. Some instruments needed to be recalibrated. One valve needed to be replaced, but must wait for the right opportunity. Once controllers are tuned, the following daily reports identify whether the tuning adjustments made the controller performance better, or whether perhaps additional tuning may be required. It is the consistent monitoring on a daily basis of controller performance that minimizes maintenance costs, and helps optimize plant operation.

Having tuned, calibrated, repaired, or replaced all poor performing control loops as part of normal day-to-day procedure, step-testing could begin.

3. Tai-Ji Online: The Identification Method

Dynamic models play a central role in MPC technology. Typically identified linear models are used in an MPC controller. Industrial experience has shown that the most difficult and time-consuming work in an MPC project is step testing and model identification. Moreover, in MPC maintenance, the main task is model identification. A traditional plant identification test can take several weeks. The quality of collected data depends heavily on the technical competence and experience of the control engineer and the operator. After the test, it can take another few weeks to analyse the data and to identify models. Model identification has become a bottleneck of MPC technology and there is a growing demand for more efficient model identification methods. Some APC vendors started to respond on this demand.

To increase efficiency of process identification mainly means the reduction of plant test time and the reduction of the time needed for model identification or data analysis. Besides efficiency, it is desirable that an identification technology uses less disturbing test methods and more accurate models.

Zhu (1998) has developed a so-called ASYM method of identification that addressed these problems. The method uses multivariable tests and parametric models. Both open loop and closed-loop tests can be used. The method has been applied in many MPC projects with success; see Zhu (1998), Snow, Emigholz and Zhu (2001) and Lien, Deshmukh and Zhu (2003).

Very recently, the method is implemented in an online identification package called Tai-Ji Online or ProcessDoctor – Tai-Ji. In this section we introduce the identification method and the online identification package and discuss the potential benefits of using an efficient identification method.

1) Plant Test

Tai-Ji Online uses multivariable closed-loop test approach. Closed-loop test means that, during the plant test, some process CVs are controlled by PID loops or by an MPC controller. MV/CV data from the closed-loop test will be used in model identification. In MPC development, a partial closed-loop test can be used. One or more PID loops can be used in a partial closed-loop test. Typical examples of these loops are: top and bottom compositions, temperatures (pressure compensated), and levels. In MPC maintenance, the existing MPC may still work reasonably well. It can be used for the test. The use of closed-loop tests can reduce disturbance to unit operation and at the same time increase the information content in data.

The planned test time is related to the process settling time and to the number of MV's. The final test time is determined by model validation. When compared with the traditional step test approach, 70% test time can be saved, because many MVs are tested simultaneously. The test signals are modified GBN (generalised binary noise) signals.

2) Model Structure and Parameter Estimation

First a high order ARX (equation error) model is estimated. Then a frequency domain model reduction is used to arrive at a low order model. The final model is in a Box-Jenkins form. See Zhu (1998, 2001) for details.

3) Order Selection and Delay Estimation

The best order of the reduced model is determined using a frequency domain criterion ASYC which is related naturally to the noise-to-signal ratios and to the test time; see Zhu (1998). The basic idea of this criterion is to minimize the total model error by equalizing the bias error and the variance error of each transfer function in the frequency range that is important for control.

Process delays (dead times) are estimated as well. Delays are estimated by trying various delays in model identification. The delays that minimize the simulation error loss function will be used.

4) Model Validation

The goal of model validation is to test whether the model is good enough for its purpose and to provide advice for possible re-identification if the identified model is not valid for its intended use. Simulation is a common validation tool in many industrial packages. This approach is very questionable for multivariable closed-loop test data.

Based on an asymptotic theory (Ljung 1985 and Zhu 1998), a 3-σ bound can be derived for the model frequency response of each model. The error bound is a function of the MV step size, test time and MV power spectrum.

In model validation, the relative size of the error bound is compared with the model frequency response over the low and middle frequencies. Then each transfer function is graded A (very good), B (good), C (marginal) and D (poor or no model). Then the model validation is done using the following rules:

- If most, say, 90% of the expected models are with ‘A’ and ‘B’ grades, the rest of the expected models are with C grade, models can be used in the MPC controller and identification test can be stopped.
- If the above condition is not met, continue the test and, possibly, adjust the ongoing test.

In Tai-Ji Online, the ongoing test can be adjusted by: 1) change MV step sizes and 2) change the average switch time of the test signals. These changes are made so that, at end of the test, most expected models become A and B grades.

5) Tai-Ji Online Implementation: ProcessDoctor – Tai-Ji

Tai-Ji Online consists of two parts: the testing device and model identification device; see Figure 3.1. The testing device generates test signals, carries out the plant test automatically and collects process data; the model identification device carries out model identification automatically using collected process data available at the moment, validate models and provide adjustment for the ongoing test. The test device works at a fixed sampling interval, say, 1 minute. The model identification device works at an interval of one to two hours, or can be started manually. The two parts are connected seamlessly for the user so that the whole identification procedure is done online and automatically.

However, if necessary, each part can also be executed separately. Tai-Ji Online is implemented on the platform of ProcessDoctor™ of Matrikon Inc. Hence it is also called ProcessDoctor – Tai-Ji. The connectivity and software infrastructure of ProcessDoctor™ are used to provide real time connection to various DCS systems, databases, user interfaces and trending tools. Figure 3.2 shows a Tai-Ji Online configuration in ProcessDoctor™.

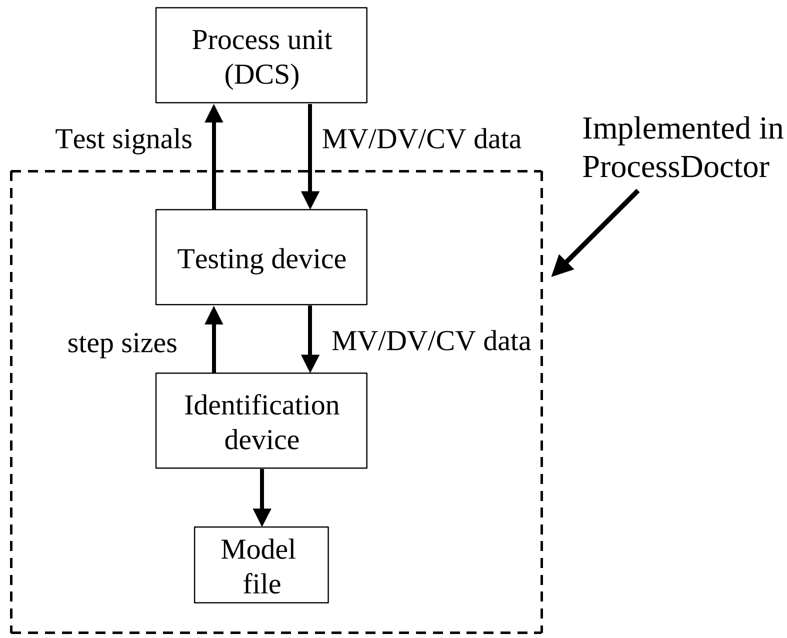

Figure 3.1 Block diagram of Tai-Ji Online

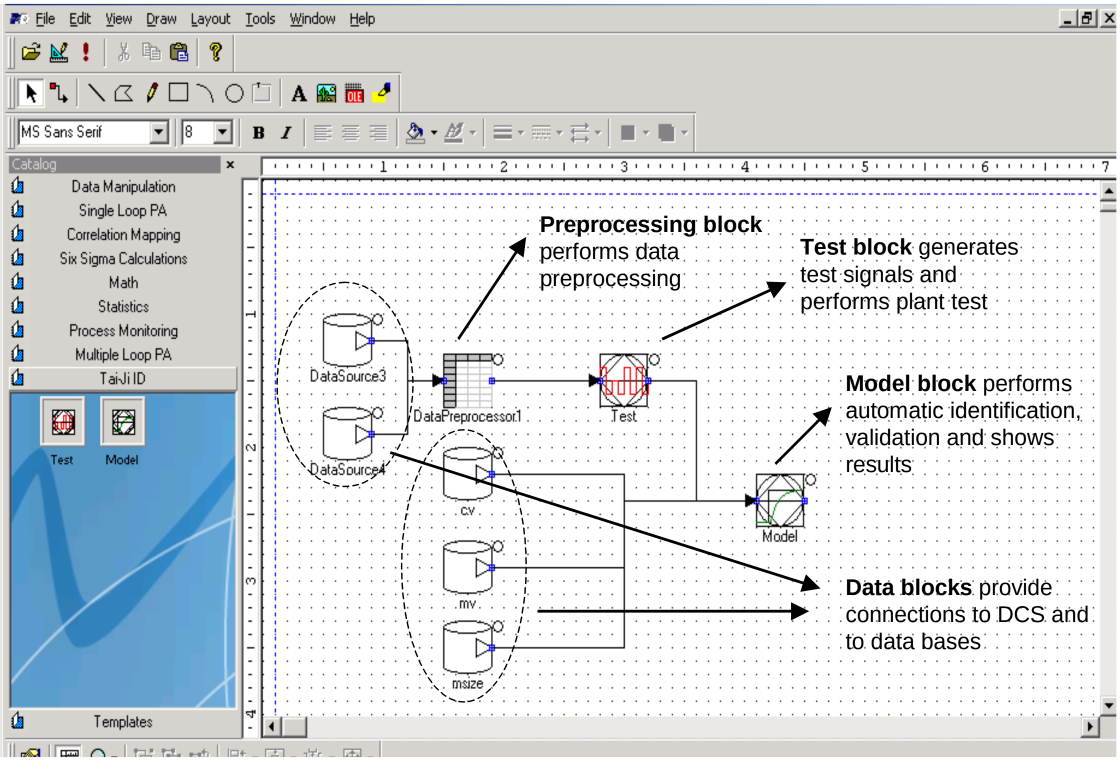

Figure 3.2 Tai-Ji Online configuration in ProcessDoctor

4. Closed-Loop Identification of Crude Unit No. 6

1) Plant Test

The Hovensa crude unit No. 6 (CDU6) is a 190 MBD crude unit that processes various grades of Venezuelan crude and other less heavy crude blends. An existing MPC application has been operational since 1996 and was in need of model updates encompasses the feed preheat, heaters, crude tower and stabilizer. The primary objectives of the MPC application are to:

1) maximize crude charge,
2) meet product specifications,
3) maximize crude preheat train efficiency and balance heater passes,
4) minimize transient periods during crude switches and product grade changes.

The revised MPC design includes 34 manipulated (MV), 7 disturbance (DV), and 90 controlled variables (CV).

Step testing was performed by moving all manipulated variables simultaneously with the current MPC controller still ON. This method provides the following major advantages:

- Step testing all variables simultaneously, 24 hours a day, significantly reduces step-test time, and providing far richer data set for model identification.
- Step testing with the MPC controller still ON reduces disturbances to the process unit as the MPC controller remains in-service and in control.
- Console operators contribute to the testing in a more meaningful manner as they are less stressed by the almost transparent step-testing method and can focus on operating the plant without feeling overloaded.
- Control engineers monitor and make step-testing adjustments without intrusion to the console operator daily work routine.
- Models can be identified after the first 24 hours of step testing to determine model qualities (graded as A, B, C, or D models) which provides for instant feedback as to which models are good and which need improvement, thus allowing for the adjustment of variable step test size on the models needing more information.

6CDU step testing, stepped all 33 active MV's simultaneously. After the first 24 hours of testing, model identification was performed to check the models. Analysis of the models revealed 15% of all models were already defined as an "A" model. After 48 hours of step testing, and adjusting step test sizes, 40% of all models were graded as "A" or "B" models. The step-tests were stopped after only 4 and one-half days.

2) Initial concerns about multivariable and automated testing method

Although the Crude unit No. 6 MPC revamp project was the first to take advantage of a multivariable and automated testing method at Hovensa, there was minimal apprehensiveness in the use of the new technology. Initially, the APC engineers did take advantage of around the clock control engineer coverage to help build operations confidence that the step-testing impact to the crude unit would be minimal (almost transparent). There were many concerns about multivariable and automated testing method:

i) Data quality was a major concern because independent variables are moved randomly. These random "multivariable" moves result in "unclear" CV moves as opposed to the clean CV response obtained by a single MV step move.

ii) Steady state gains calculated using the automated "multivariable" step-test might not be that accurate because of the too many frequent "short duration" moves.

iii) Correlated moves in the multivariable step-test may cause problems in model identification.

3) Benefits of the new identification technology

The original Crude No. 6 MPC controller was designed using models developed via the traditional step-test. During this step test using Tai-Ji Online, the existing controller has done a good job in stabilizing the unit operation. Operators were also encouraged to move any MV at any time as needed to keep the unit within the normal operating range. The advantages of the Tai-Ji Online automated plant testing and automated identification tools are given below.

A) Faster test: Tai-Ji Online plant-test duration is extremely shorter compared to the traditional method on a typical crude unit that usually takes several weeks and requires round the clock coverage from APC engineers. Since the step test is automated and seamlessly interfaces with the existing MPC application, not much intervention with the operators is needed to implement the moves. The APC engineer coverage is minimal to moderate and need not be round the clock. The automated test is appealing to the console operator since it is less intrusive and allows the operator to focus on running the plant as opposed to being an integral participant of the plant-test. There is no competing for operator attention.

ii) Easy model development: Tai-Ji Online model development features are attractive and appealing as they are easy and straightforward. The model identification takes a few hours in contrast to several days of traditional method. The quality of the models can be even verified during the actual plant test progress. Based on this model quality some of the move sizes can be adjusted to improve the model quality if needed.

iii) Better way to select models: Tai-Ji Online enables the APC engineer to select the models in easy and sound manner. It mathematically quantifies the quality of the models by assigning the letter grades (A through D; A very good model and D poor model). In addition, this model quality grades are easy to comprehend and review with the process operations. Tai-Ji Online uses frequency response error bounds are especially useful to the APC engineer in selecting or modifying the models.

iv) Low cost solution: Overall the Tai-Ji Online approach is a low cost solution to the MPC model identification. The duration of the plant-test is directly related to how many plant upset conditions are experienced during the testing i.e. crude switch. Sometimes the window of testing opportunity is relatively short. The advantage offered by Tai-Ji Online, is that the testing window is successfully reduced while giving a good sense of recent plant-test status. It saved 80% of the actual step-test time and several weeks of APC engineer time for the model development.

The Tai-Ji technology supports the cognitive tasks of monitoring and diagnosis of plant-test progress to ensure quality of models as testing moves forward.

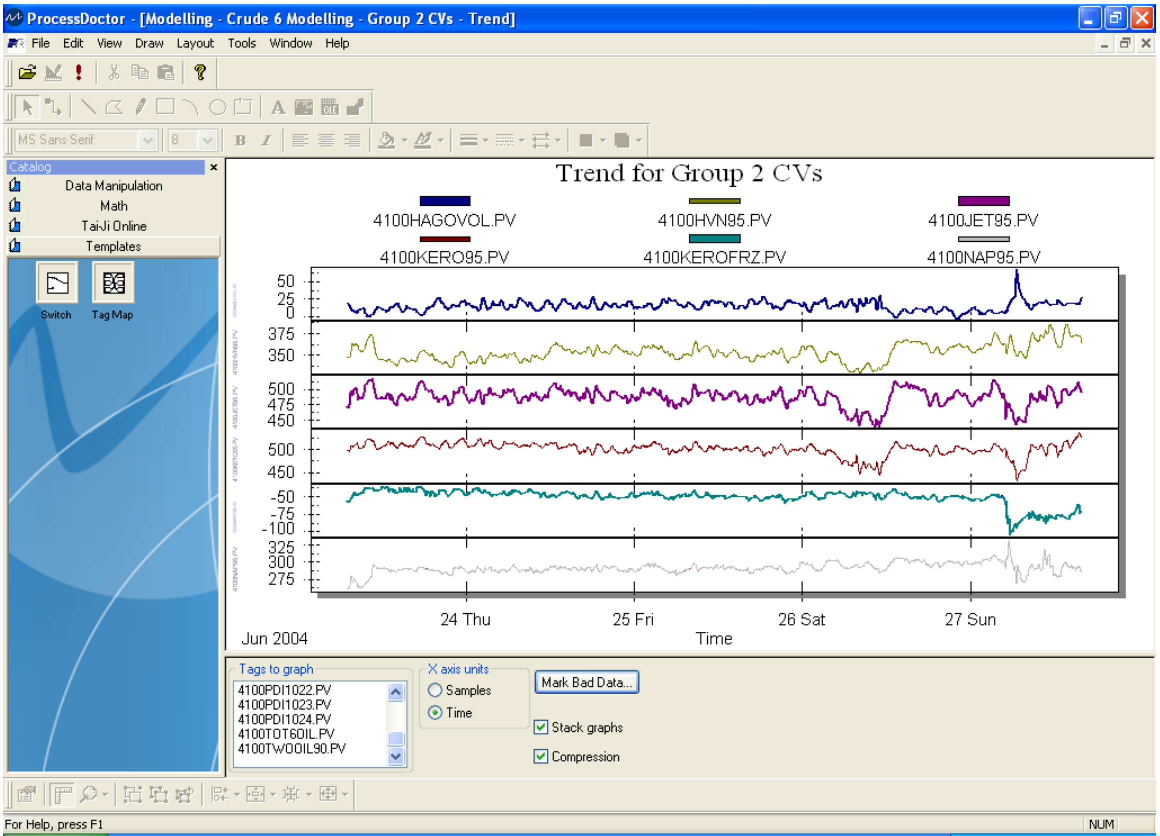

Figure 4.1. CV data for selected CVs during the step test.

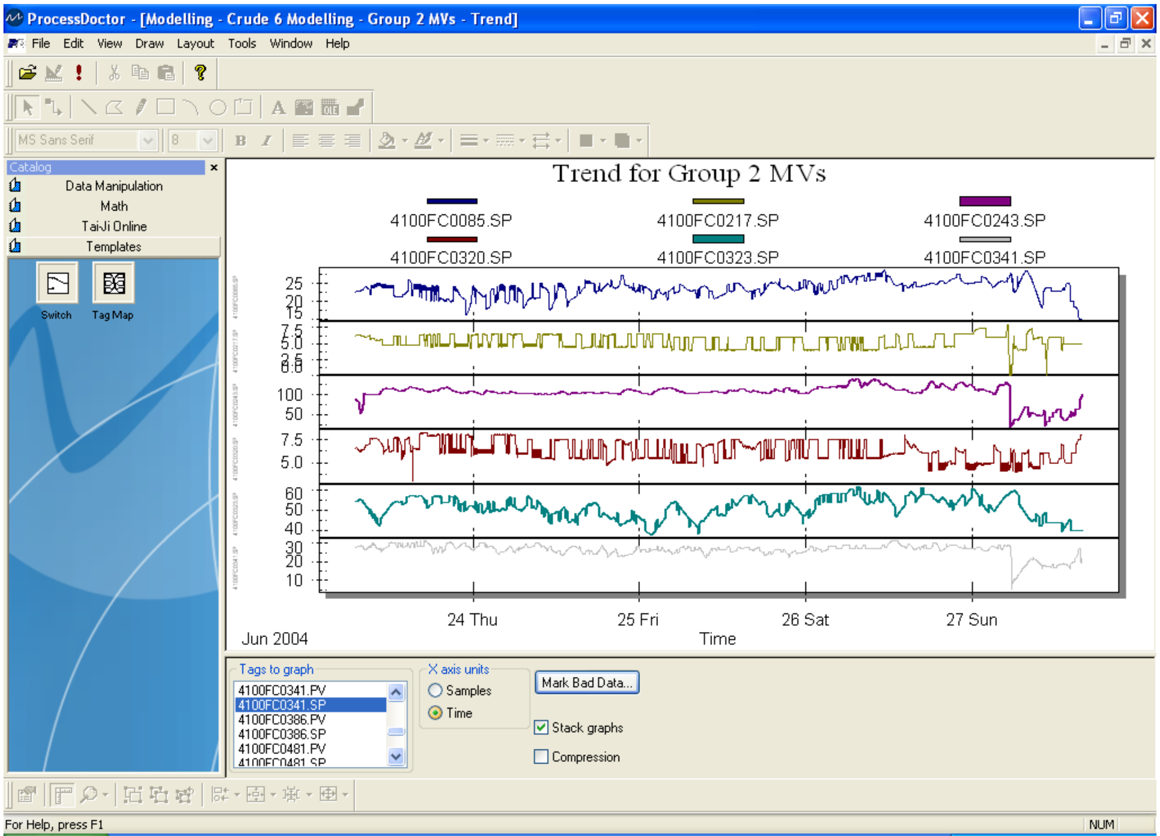

Figure 4.2 Selected MV data during the step test

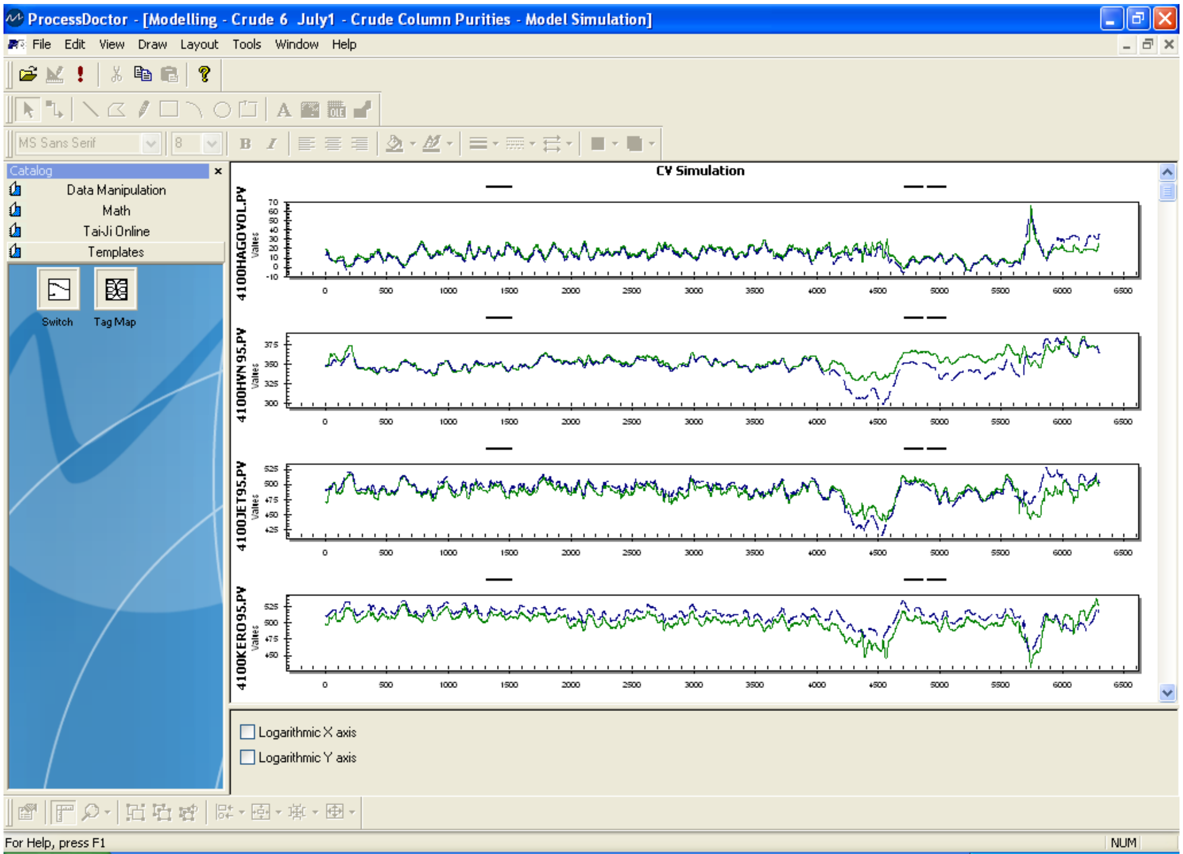

Figure 4.3 Model fit for selected CVs

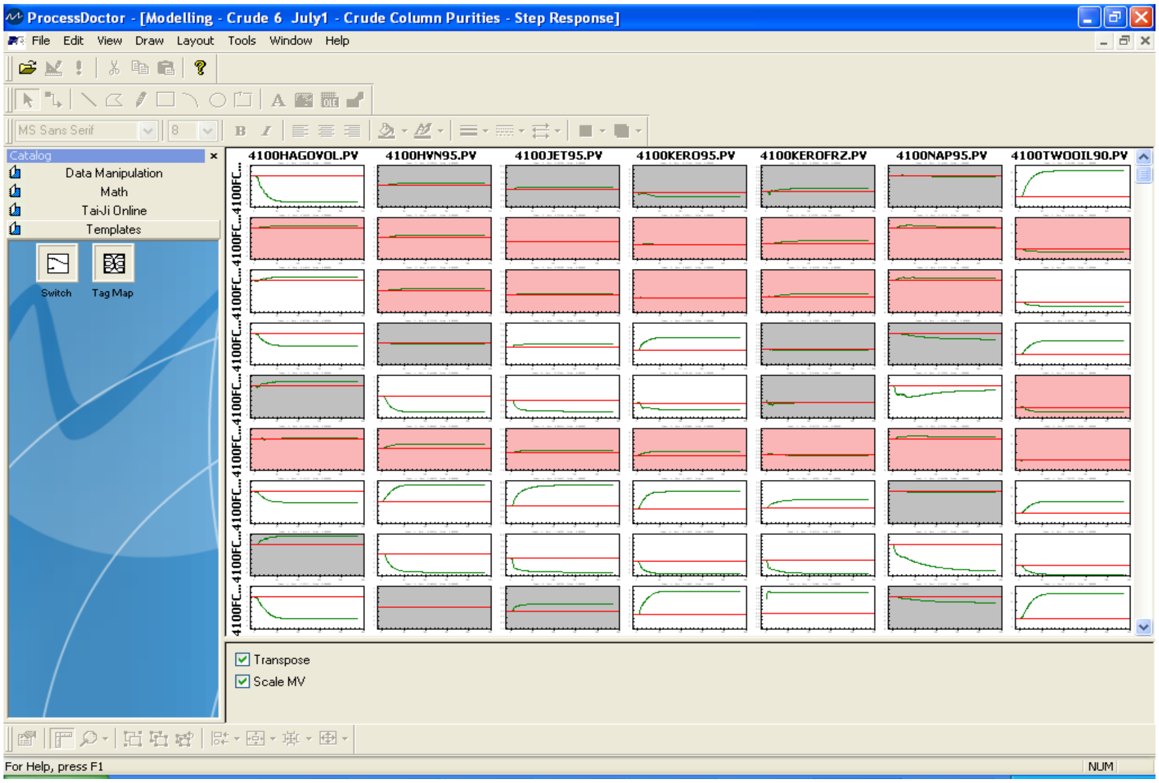

Figure 4.4 Step response plots for selected models (pink background: Model expected but model quality not satisfactory, white background: model expected and good quality model identified, grey background: no model expected)

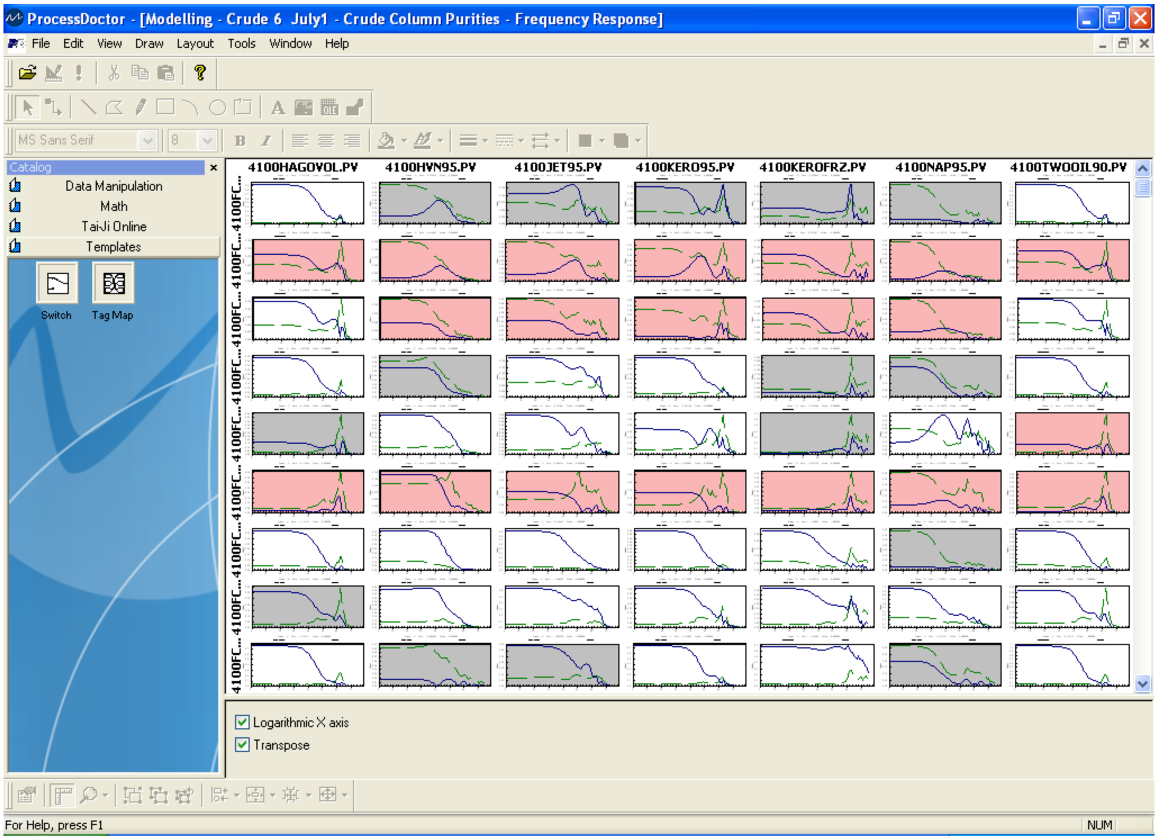

Figure 4.5 Frequency response plots for selected models. (pink background: Model expected but model quality not satisfactory, white background: model expected and good quality model identified, grey background: no model expected)

5. Conclusions and Discussion

Hovensa has the benefit of making a direct comparison between the step test of 6CDU versus the traditional "one MV at a time" step test of 5CDU performed at the end of last year. Conservatively speaking, the 5CDU step test took 1 month of step testing, and 1 month of model identification. 6CDU required just over 4 days of step testing, and 1 day of model identification. The extra day for model identification of 6CDU was due to the fact that we had some variables that required some special attention. However, the majority of the models were completed by the time the step test ended. This represents an overall reduction in time effort of approximately 92%.

The CDU6 MPC retest project demonstrates the technology, ProcessDoctor and ProcessID-TAIJI, has become an enabler of implementing MPC in a more efficient manner. We have shown that the efficiency of MPC projects involving step-testing and model identification can be increased significantly by using the regulatory benchmark analysis tool and the online closed-loop identification technology. In conducting a MPC project using this technology base, plant-tests, take a reduced toll on the process and the console operator's faculties, model quality can be improved and the overall workload of control engineer is reduced. The models generated by Process ID-TaiJi result in cleaner, more crisp models which require much less control engineer judgement regarding smoothing manipulation before applying the new model. The regulatory controls monitoring and benchmarking tool combined with the online closed-loop identification technology allow control engineers the technology and knowledge base to sustain optimal control system and MPC benefits throughout the entire unit run cycle.

As the technology matures and evolves, these tools may run automatically to check both regulatory and MPC controller health, suggest new models, which can ultimately lead to an adaptive, or self-maintaining MPC application.

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