APC BEST PRACTICES: USE OF ADAPTIVE MODELLING TO MAINTAIN AND REVAMP DMCPLUS CONTROLLERS

A new tool ' Adaptive Modelling ' developed by ENI embodies best practices in model maintenance workflow and completes a suite of tools that enable a proactive maintenance approach for APC applications through the online monitoring of Key Performance Indicators (KPI's), for both controllers and models. ENI R&M revamped a Hot Oil circuit controller section in just a few hours and the performance of the unit showed a significant economic benefit. This article enumerates how this was achieved.

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ENI Refining and Marketing (ENI R&M), like many other operating Companies, was finding it challenging to properly maintain its large installed base of existing APC applications with a reduced workforce. They were actively looking at new tools and methodologies to improve efficiency. ENI R&M has been working with AspenTech for around 15 years in developing new Advanced Process Control applications and to properly maintain the more than 50 existing APC controllers in its Refineries. After discussion, the decision was made to look at Aspen's Sustained Value tools and services for APC: performance monitoring, automated testing and adaptive modelling.

Frequent Lube Oil production type changes were being made to capitalize on supply chain opportunities. The limited APC resourcess were struggling to keep up, as these changes required updates to the controller models to keep the APC solutions generating the highest value. After ENI R&M tested adaptive modeling in its Livorno Refinery with good results obtained, they decided to deploy in its other Refineries

ENI R&M Livorno Refinery

The Livorno Refinery is a Fuels and Lube Oil Refinery with a significant number of APC applications installed. In the following picture a simplified Refinery layout is shown in the next page.

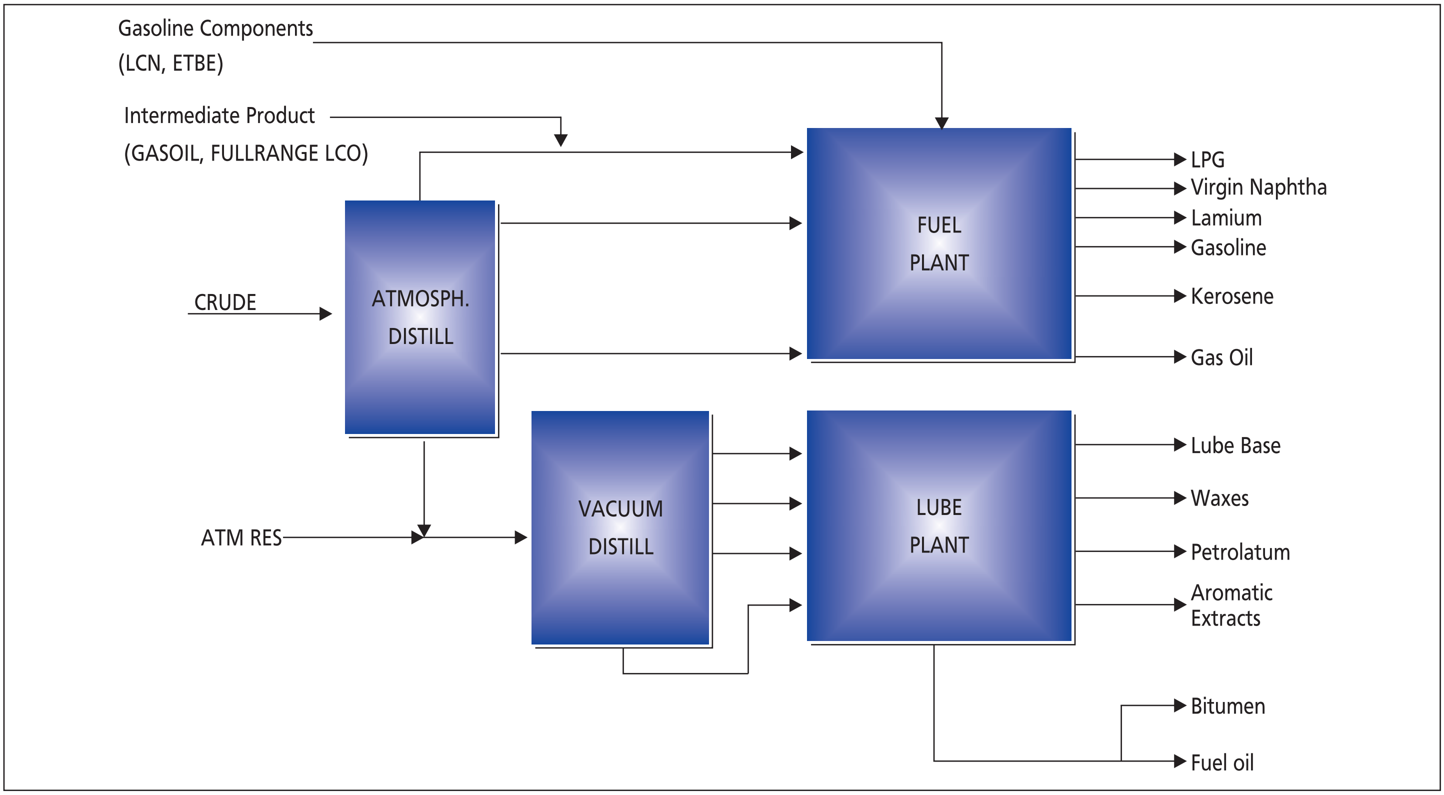
The Refinery runs 13 medium to large scope DMCplus MPC controllers and 24 Aspen IQ Inferential modelling applications for a total of:

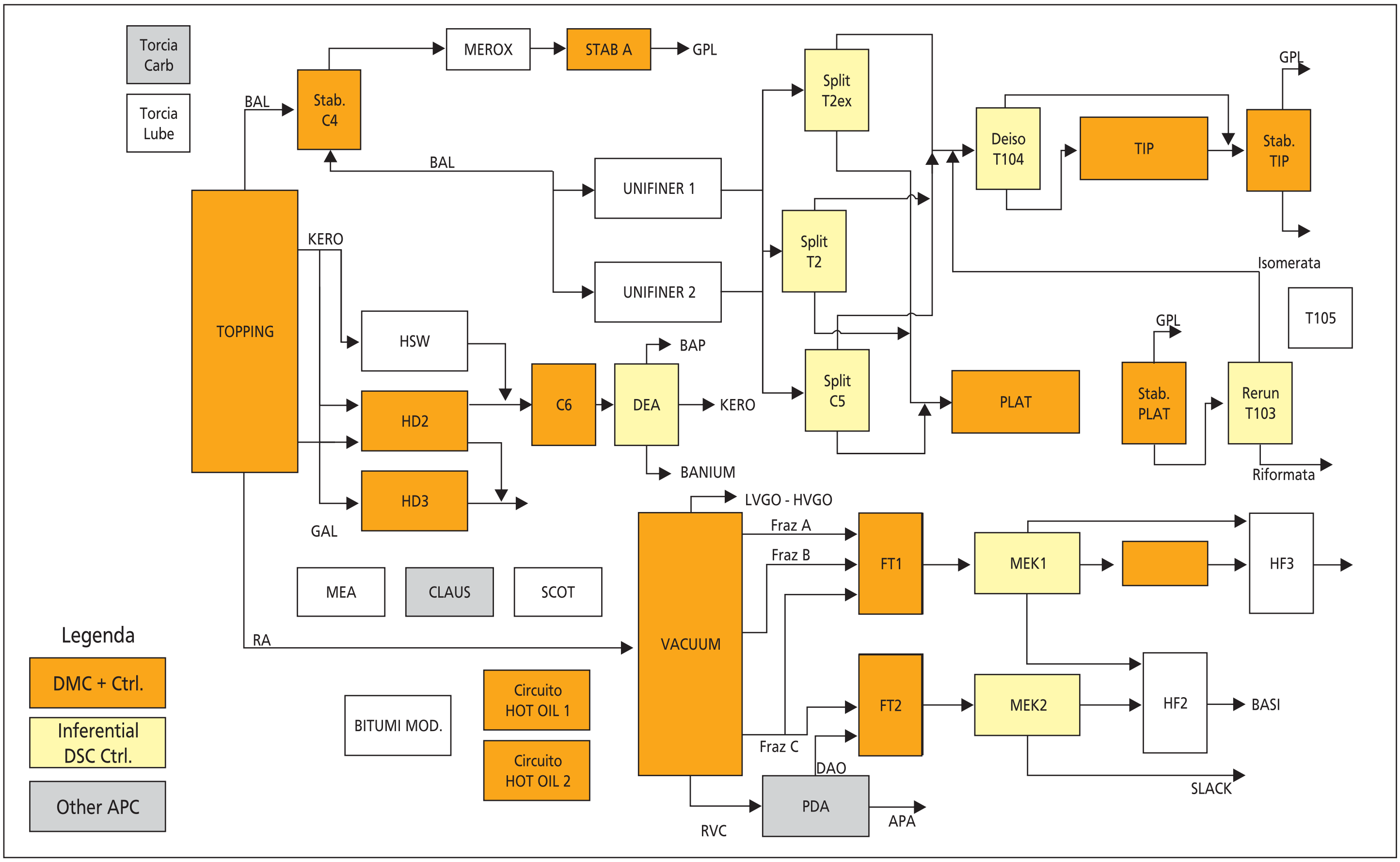
- 210 MVs (Manipulated Variables)
- 92 Inferential Properties

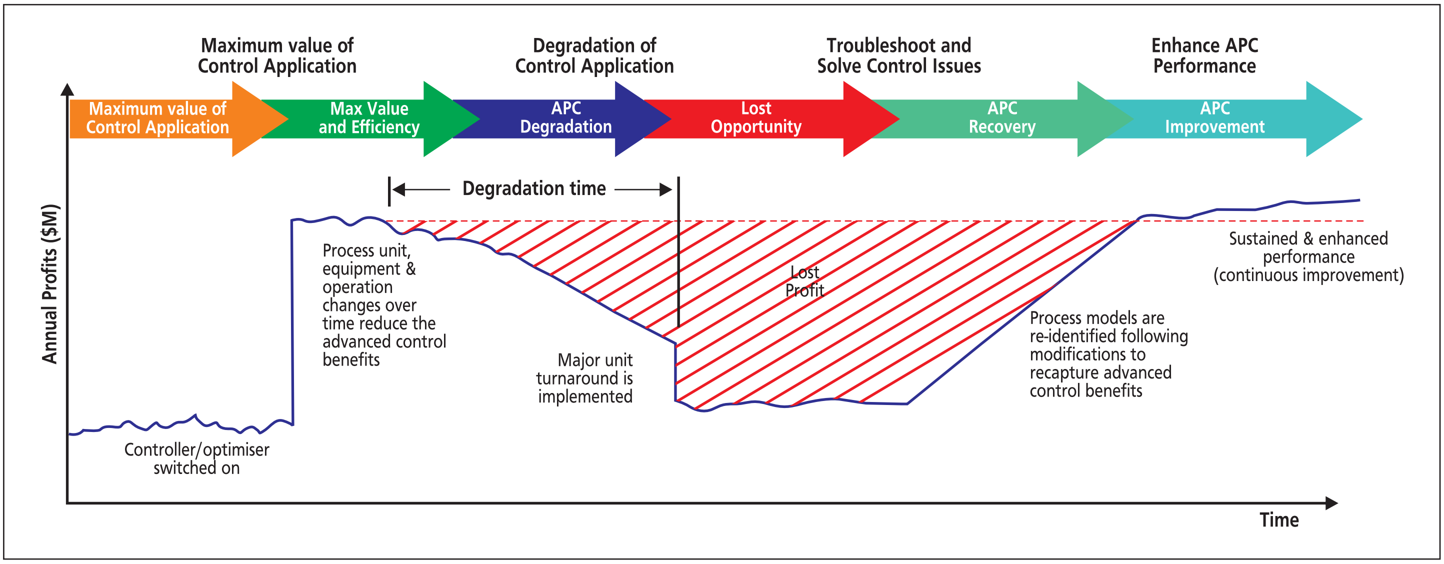
The Refinery was ranked 1st in a Solomon 2006 APC/Automation comparative study that involved 18 refining companies and a total of 36 refineries, but it is still looking to improve. In the following picture, the APC coverage is reported and it can be noticed that APC applications cover all major process units and additional controllers are currently planned for the remaining plants.

Being a Lube Oil Refinery, there are frequent lube oil type production changes that affect Operations and hence the APC application's performance. This is a significant change, and is in addition to the usual crude switch and crude quality disturbances.For these reasons, APC maintenance for best performance is a continuous task that keeps the site APC engineer busy.

5.2 Mton/year Crude Capacity, 610 Kton/year Lube Base Production







Sustaining APC Benefits

It's something of a misnomer to say that APC applications require maintenance. If nothing in the plant ever changes, then almost no maintenance and no model updates are then required. However, when significant changes are made to the process, or the feedstock characteristics change significantly, then the APC models must be made 'aware' of these changes. When model updates or regular controller maintenance due to significant process and instrumentation changes are not done, the performance of the APC system starts to degrade.

Pictures like the one above are well known and all bring across the same message: poor maintenance, sooner or after, inevitably jeopardizes the APC investment.

There are many potential reasons for performance degradation, but some of the most likely are listed below:

- Staff mobility
  - Internal staff, originally familiar with the application, moves to a different position.
  - New staff may not be able to immediately support the application.
  - New staff may require significant training to be able to understand and support the application.
- Process changes:
  - Processes are often changed and these changes can affect controller performance.
- Catalyst changes, exchangers fouling, valves and other instrumentation changes.
- Routine maintenance on instrumentation and equipment.
- Economic changes: These affect the steady state solver solutions, and if they are not recognized and accommodated, performance may degrade or the controller may even lose money instead of accumulating profits.

Typical signs of performance degradation are:

- Sub-Controllers in OFF status; MVs (Manipulated Variables) or CVs (Controlled Variables) routinely out of service, or in DCS LOCAL status.
- Some CVs never reach SS (Steady State) targets before SS targets change again.
- Some CVs remain outside limits for extended periods.
- Many MV limits clamped or MVs at setpoint i.e. with high/low limits set to identical values.
- Some MVs show "noise" response with frequent change of direction.
- Almost all MVs in a controller are moving on every controller execution.
- MV dynamics are often being limited by maximum move limit.
- CV prediction error tends to be positive, then negative for extended periods, indicating model mismatch
- Cycling CVs or MVs.
- Unstable LP solution, i.e. steady state targets flip frequently.
- Primary controls not holding set points.
- Control is too aggressive even with insignificant CV error.
- Controller is overly aggressive with secondary objectives.

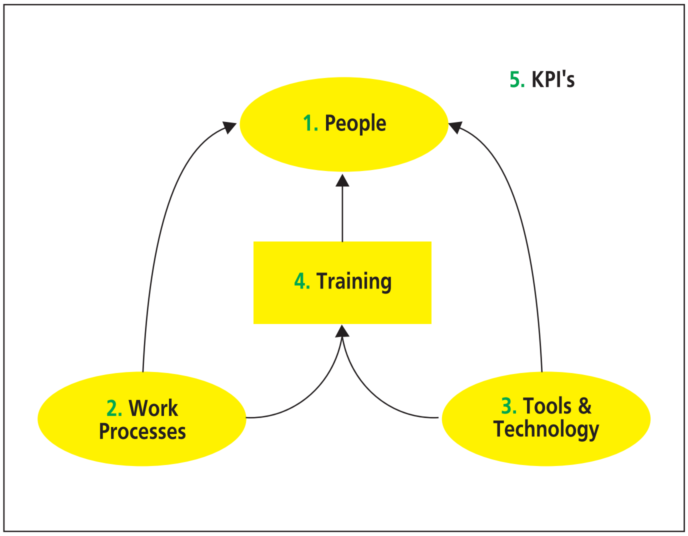
The typical manual APC maintenance workflow is labour intensive and too inefficient as it is basically reactive and not proactive. The APC maintenance workflow goes through the following major steps:

1. Control
   - Something changes in process or in the operating mode.
   - Controller begins to oscillate or perform badly (maybe just in some areas, and only under some circumstances).
   - Operators start clamping MVs or taking out MVs/CVs, or entire Sub-controllers.
2. Detect
   - Control engineer is usually not automatically alerted about the problem.
   - Operators will likely call for help only when problem becomes too severe to tolerate.
   - Control Engineer may spot the issue while checking trends or controllers limits or passing by the Control Room.
3. Diagnose
   - At some point the control engineer is somehow notified by a keen operator, or spots the issue himself.
   - The control engineer will attempt the manual diagnosis by speaking with operators and analyzing data either online, or offline on his desktop.
4. Repair
   - Diagnosis is completed.
   - Problem may simply be ignored or manually repaired and very often a sub-optimal solution is taken (e.g. why invest days in retesting a part of the process unit if I can simply detune the controller, or manually adjust a couple of gains?).
   - Small problems tend to build up till parts of the controller or the entire application are switched off.
   - A major revamping step then has to be undertaken.

The Control Engineer usually needs to manually extract process data to isolate the root cause. Once the nature of the problem has been determined, the manual model building method increases the time it takes to correct the problem and return the controller to full service. If maintenance is deferred, the problems build up until a major revamping activity has to be undertaken to fix all the issues that have been slowly accumulating. This approach is very inefficient and causes a loss of benefits that can be as high as 50-60% during the 4 or 5 years application lifecycle.

With some supporting automation, we can significantly streamline this workflow and reduce the time and effort needed to keep controllers at peak efficiency.

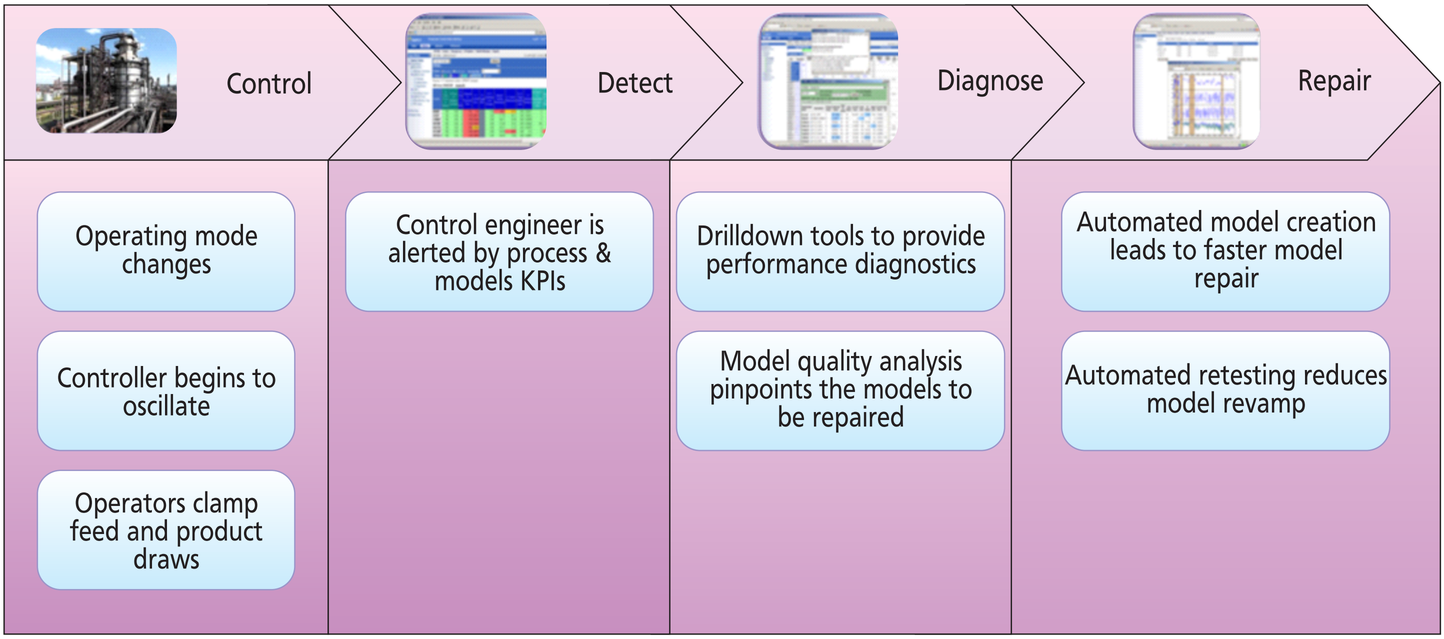
Successful APC application maintenance also requires plans and practices aligned with the business strategy and supported by management commitment, in order to ensure that tools, people and processes are in place and aligned.



- A proper APC maintenance methodology should have the following characteristics:
- Incorporate APC Best Practices.
- Minimize effort:
  - Automate and simplify maintenance tasks.
- Use proper baselines, KPIs and automated reports to continuously track performance:
  - Rapidly detect changes in performance.
  - Few KPI's, but covering both controllers and models performance.
- Use diagnostic rules to isolate root cause of performance degradation:
  - Quick assessment of problems.
- Use automated step testing to quickly generate high quality data for improved models:
  - Relieves engineering from manual testing and from "night-time engineering".
- Preprocessing rules prepare data for modeling:
  - Automated data cleaning tasks, consistent preprocessing.
  - Minimize the need to manually slice data.
- Automatic generation of new models:
  - Generate new models without requiring extensive engineering effort.
- Rules for rapid model assessment:
  - Quickly assess improvements.
- Avoid manual data collection and moving data through different servers or using flash memories, or other media, to cross firewalls.
- Be simple and streamlined in order to be proactive instead of reactive: make it a regular task, and do not just react to events.

Technology keeps improving and tools that enable a proper proactive maintenance methodology with the characteristics described above are now available on the marketplace. With

Automated APC Maintenance Workflow



that kind of automation the four steps in maintaining an APC application described in the previous section can now performed differently, as depicted below.

Sustained Value Tools

The sustained value tools supporting detection, diagnostics and repair are:

Performance Monitoring (Aspen Watch): with the capability to historize controller and process data, build baselines, calculate controller and process KPI's and automate reporting. Through these performance KPIs the user can rapidly detect when the process is not operating at peak performance. Model KPIs show the specific MV/CV pairs that are contributing to poor performance.

Automated Step Testing tool (Aspen SmartStep): automates process step testing while maintaining the process within specifications at all times with a Model Predictive Controller. This tool supports single and multi-test methods. It produces richer data quicker than manual step testing as it enforces APC best practices and estimates the largest possible MV steps while still maintaining the process within constraints. Much of the plant testing can now be done without engineering supervision.

Adaptive Modeling tool (Aspen Adaptive Modeling) automates the maintenance lifecycle of a controller by providing the ability to collect historical data, automate calculations for data cleaning, schedule online model quality assessments, run standard and custom KPIs to assess model quality, model diagnostics and online model identification. It is not a black box and it does not automatically update models but it enables engineers to do so efficiently.

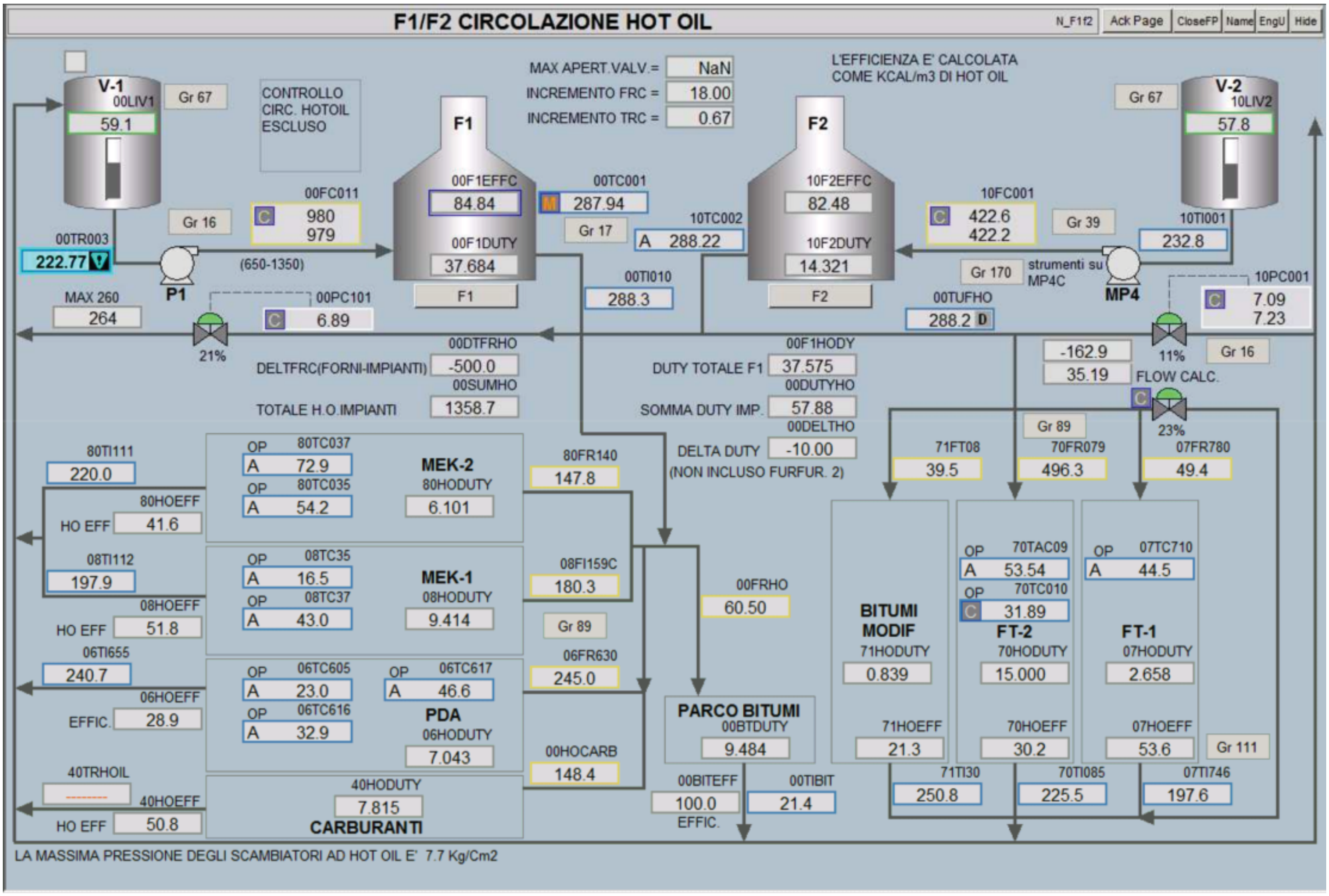
All of this automated workflow is performed on line from a Web interface directly on the running controller without the need to start a data collection task, extract data, model or tune offline, move data between systems, or start or stop applications. The process is fully streamlined and it enforces APC Best practices at all stages while still giving the APC engineer the capability to control and influence the results, while eliminating routine manual activities.

The methodology is designed to enable APC end-users to perform all the regular, proactive APC maintenance on their own, without involving an external consultant. End users should involve, if required, an external consultant only in case of major process revamps, and never for routine maintenance, since the tools and methodology now also enables the non-expert to maintain his APC applications efficiently.

Livorno Refinery Proof of Concept

Amongst the Livorno Refinery APC applications there are also two hot oil circuits (HOTOIL1, HOTOIL2). First circuit delivers around 65 MM Kcal/h and the second around 25 MM Kcal/h to many reboilers and other exchangers in many Plants all around the Refinery.

Below is a simplified screenshot of the circuits.



The evaluation of adaptive modeling focused on HOTOIL1 circuit controller and mainly on F1 furnace.

HOTOIL1 Controller Design:

- 11 MVs; 54 CVs; nearly 100% service factor:
  - Most MVs are related to F1 furnace.
  - Most CVs are valve outputs of hot oil users control loops.
  - Controller originally deployed in 2005.

- Controller objectives and benefits:
  - Operations flexibility and maximization of delivered duty whenever required.
  - Disturbances rejection.
  - Stability of temperature and pressure of the loop.
  - Optimization of furnace combustion.

- Controller main constraints:
  - Loop pressure and return temperature.
  - Feed pump capacity.
  - Furnace skin temperature, draft and excess O_2.

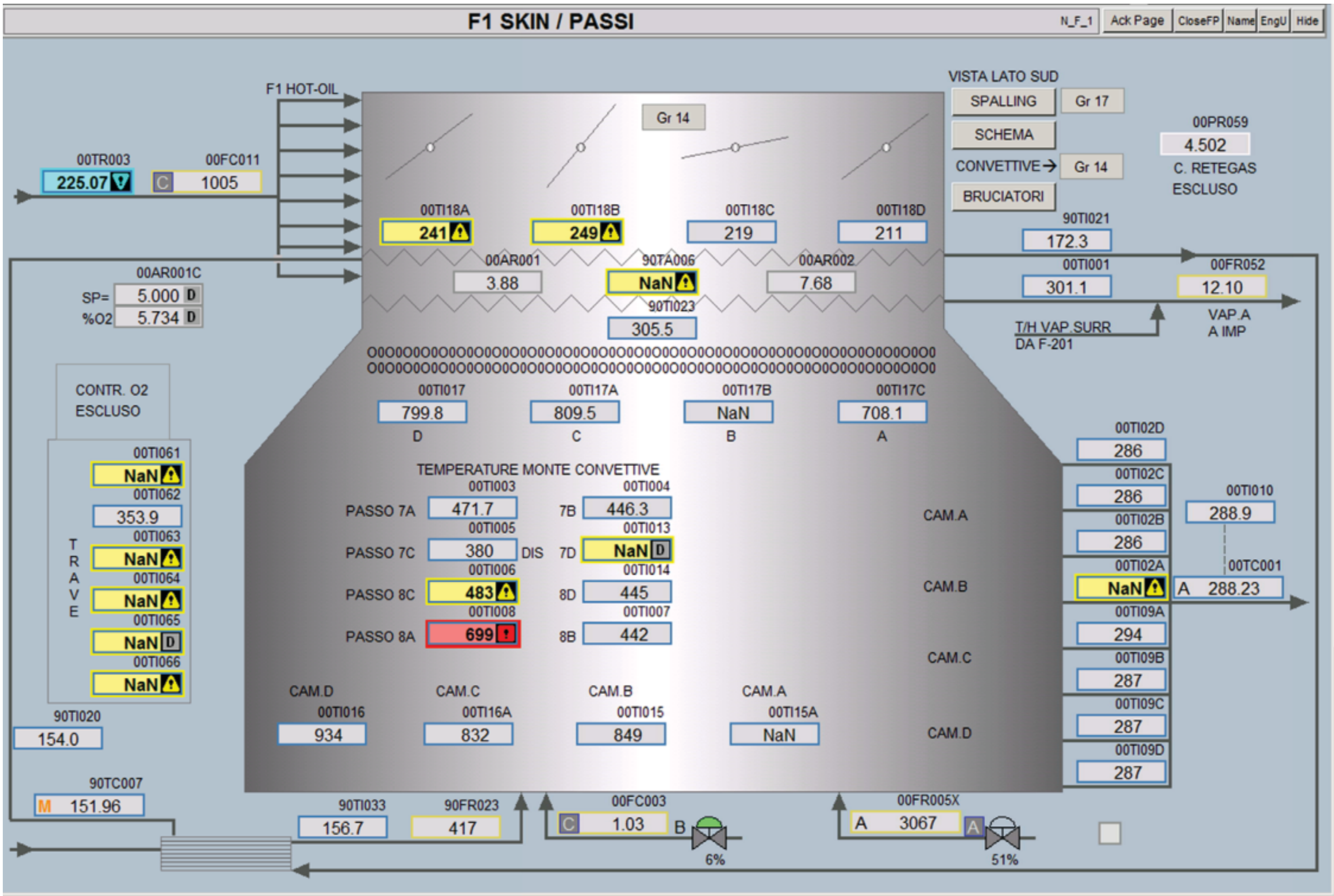
F1 furnace:

- 4 cells, 8 passes; mixed fuel gas / fuel oil burners.
- 4 dampers, 1 blower with backup.

The evaluation was conducted in a meeting room close to the control room with around 15 APC engineers coming from all ENI R&M Refineries.

The unit has been selected because:

- Efficiency control of F1 furnace in DMCplus has been running with limited capabilities for some months due to model degradation after field equipment maintenance:
  - Service Factor was still around 100%, but significant benefits were left on the table.
  - A model revamp for that section was required as the old models couldn't run closed loop anymore after the process changes.
  - Application had to be brought back to peak performance as per ENI R&M best practice policy.



MV	Description	Strategy	Constraints	Status
00DC2AOP	Chamber A damper position	COST Maximize	Chamber draft and balancing	Out of service
00DC2BOP	Chamber B damper position	COST Maximize	Chamber draft and balancing	Out of service
00DC2COP	Chamber C damper position	COST Maximize	Chamber draft and balancing	Out of service
00DC2DOP	Chamber D damper position	COST Maximize	Chamber draft and balancing	Out of service
90FC23ASP	Blower flow rate SP	COST Minimize	Excess O_2, air to fuel ratio	Overconstrained
90FC23BSP	Backup blower flow rate SP	COST Minimize	Excess O_2, air to fuel ratio	Overconstrained

- Only a little portion of the model matrix involved.
- It was an ideal candidate for an Aspen Adaptive Modeling pilot as one of the goals of the revamp project was also to evaluate within ENI R&M the new features provided through the new tool.

The evaluation itself took around 2 full days and the workflow went through the following steps:

- Controller performance assessment through baselines and KPIs (Aspen Watch, Adaptive Modeling).
- Automated Step Testing tool (SmartStep) configured and run throughout the whole process.
- As-is Model Quality assessment performed (Adaptive Modeling).

- Automated data cleaning and Case setup on the Performance Monitoring System (Aspen Watch, Adaptive Modeling).
- Model Identification iterations (Adaptive Modeling).
- Online model update and deployment (Adaptive Modeling).
- Post-revamping Model Quality assessment (Aspen Watch, Adaptive Modeling).

All this was done smoothly through a Virtual Machine connected on the ENI R&M control network and all done on-line from the Production Control Web Server operator interface. During SmartStep activity the group had plenty of time to discuss maintenance methodology, and revise baselines and KPI's.

The most interesting KPI that was discussed and enabled is a modified version of the Utilization Factor (UTL) that is available as a part of the collection of built-in KPIs in Aspen Watch. The idea of a Utilization Factor was first proposed by Kern in Hydrocarbon Processing in October 2005. This KPI, modified by ENI R&M engineers, is defined as follows:

ENI_UTL= (CCS+MFU+MOK) / IPMIND*100

where:

CCS = Number of CVs at high/low limit, setpoint, ramp or external targets.

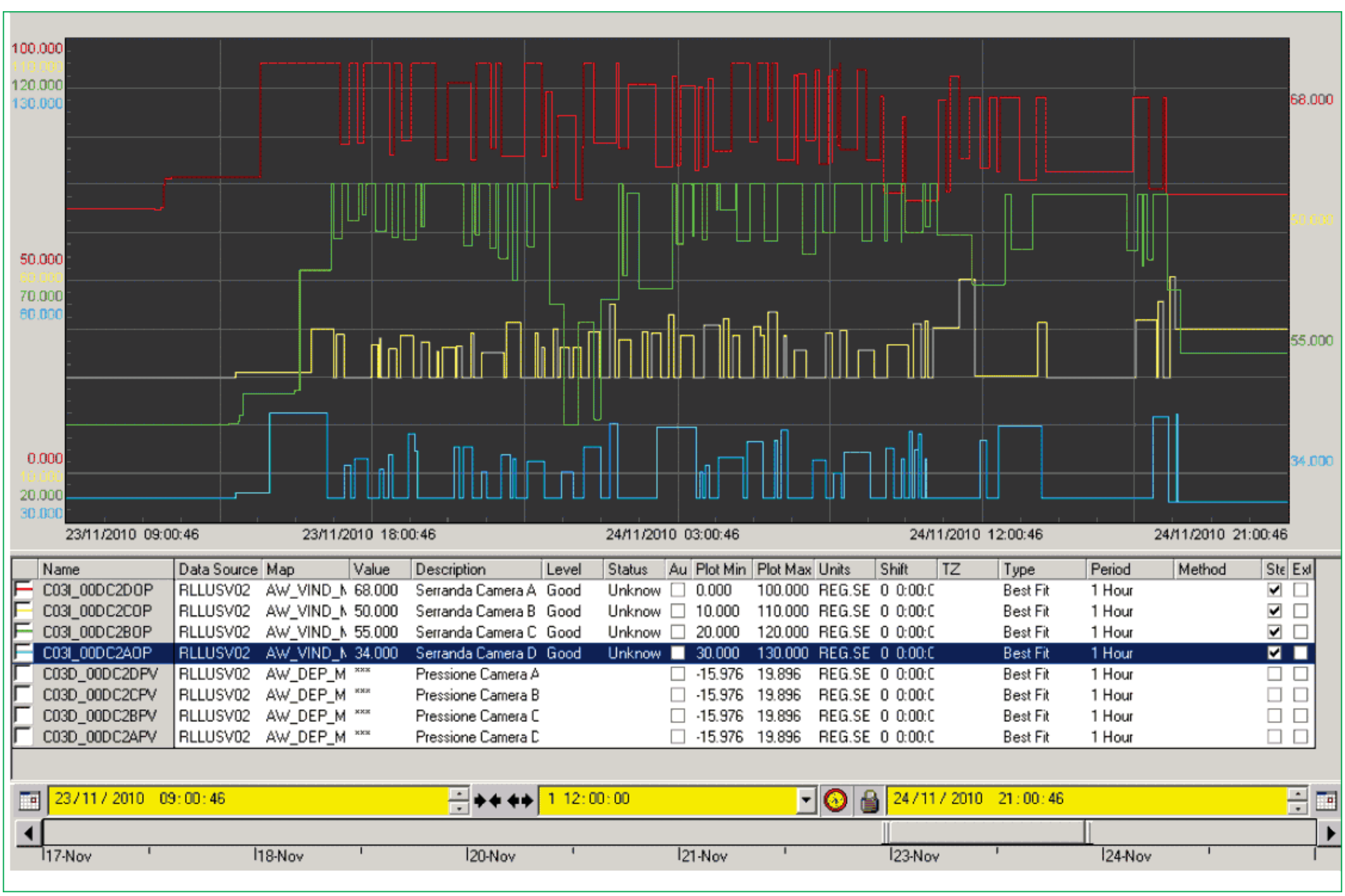
MFU = Number of MVs at external target or engineering limits.

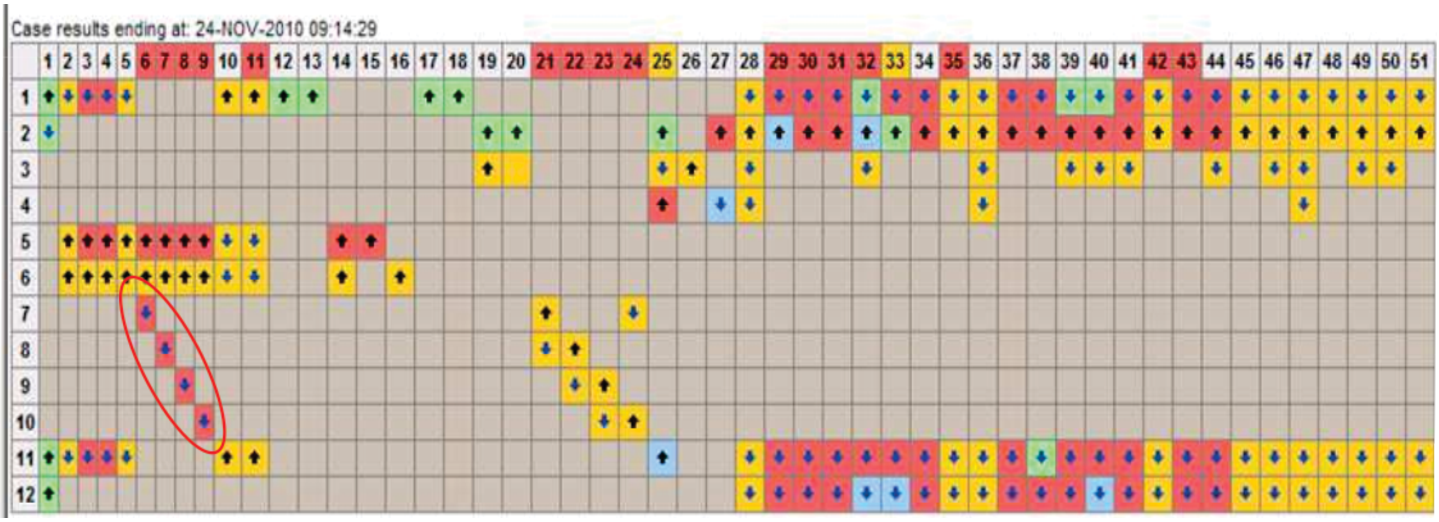
MOK = Number of MVs at min move, wound-up, in bad status or taken out of service by the engineer.

IPMIND = Actual number of manipulated variables in the controller.

A good performance for this KPI guarantees that the controller is not just simply ON, but it's actually moving and using all available MVs to push constraints, i.e., to accumulate APC benefits.

Smartstep was already enabled in the DMCplus application and little reconfiguration was required. Multitest mode was used from the beginning to test the MVs simultaneously to minimize step testing time, while minimizing MV correlation and maximizing signal to noise ratio to enhance models quality. As it can be noticed in the picture below, all MVs move concurrently, permitting models to converge very quickly.





Notice how SmartStep varied the amplitude and the average value of the MVs to ensure that the CVs stay between the CV limits. While SmartStep was testing the unit, the group concentrated mainly on the new Adaptive Modeling usage and results:

View and clean up the MQ (Model Quality) data:

- User can view the data used in Model Quality Analysis Test.
- Some data cleaning is automatically performed.
- Engineer can also manually clean the data further using web viewer.
- Calculations for automated data cleaning can be configured (e.g. when an MV is moved to DCS control or a CV control error is too high),

Run an MQ test:

- Run the test from the web viewer.
- Schedule a recurring MQ test at a designated time and interval.
- Model KPI carpet plots are automatically updated.

Configure & Run Model ID (Identification) case:

- Browse Aspen Watch database for tags to include in the ID case.
- ID case can be run on demand, or scheduled to run automatically at particular time and interval.

Review Model and Deploy:

- Multiple model ID cases can be compared with the current model directly in the web viewer.
- Bode plot analysis available in the web viewer to assess model uncertainty.
- Once satisfied, model can be assembled and deployed online.

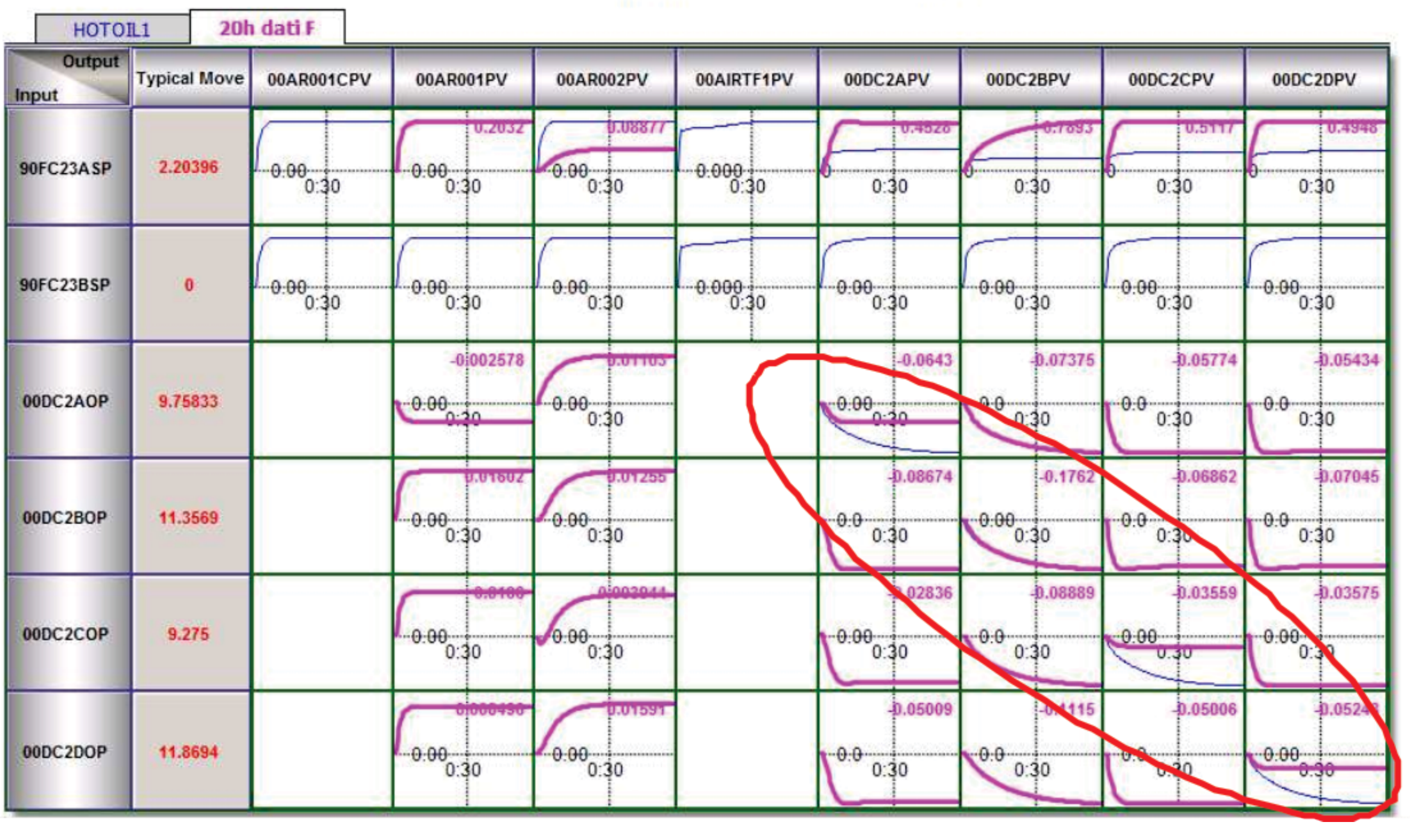
It must be stressed again that all these activities have been performed on line through a web viewer interface and using data available in the Performance Monitor database. MQ data appear as a KPI plot where each model (MV/CV pair) is flagged with different colors depending on how good the models used by the Controller are compared to those assessed with just a few MV moves. In the picture above the complete model matrix is reported and the models where the project team concentrated, are highlighted in red within an oval.

- Good (green) means that the model pair has a high degree of accuracy.
- Fair (light blue) means the accuracy is somewhere between Good and Bad.
- Bad (red) means the model accuracy is low.
- Unknown (yellow) means that a clear answer could not be derived from the data provided (i.e. likely not enough significant data).

During the evaluation, our focus was just on a portion of the matrix, and MV steps where performed only there. That is also why so many red and yellow blocks can be seen in the above matrix.

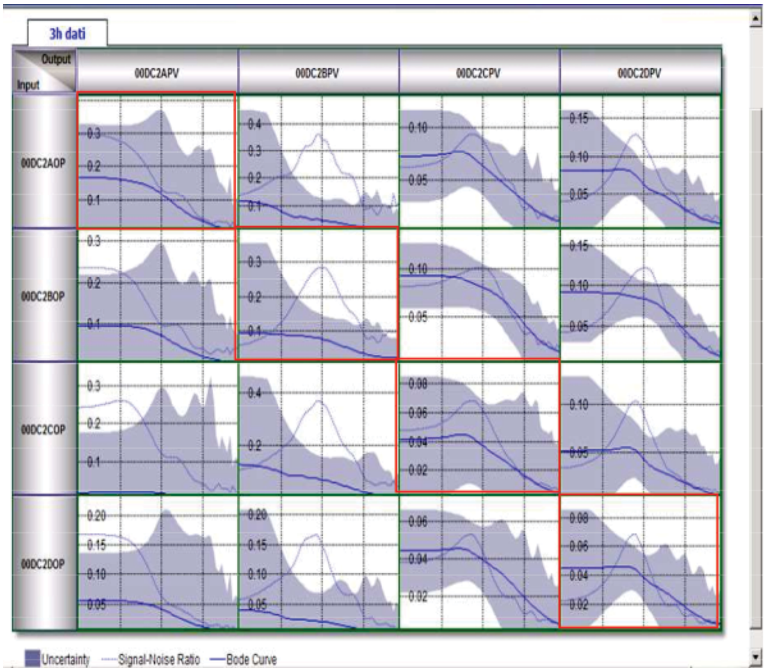
In a routine maintenance activity, 3-4 steps should be performed on all relevant MVs for Model Quality Analysis. After having assessed if/where models need further improvement (via the MQ Analysis), more steps should be implemented for the models that need to be re-identified, checking the models (ID) results every few hours. Step testing is only done for the MV's where new models are needed, and only as many as required to obtain a sufficiently accurate model. A proper maintenance routine will require testing just few a MVs, as typically models show some local degradation following an event. It's uncommon for the entire matrix to suddenly start showing model accuracy issues.

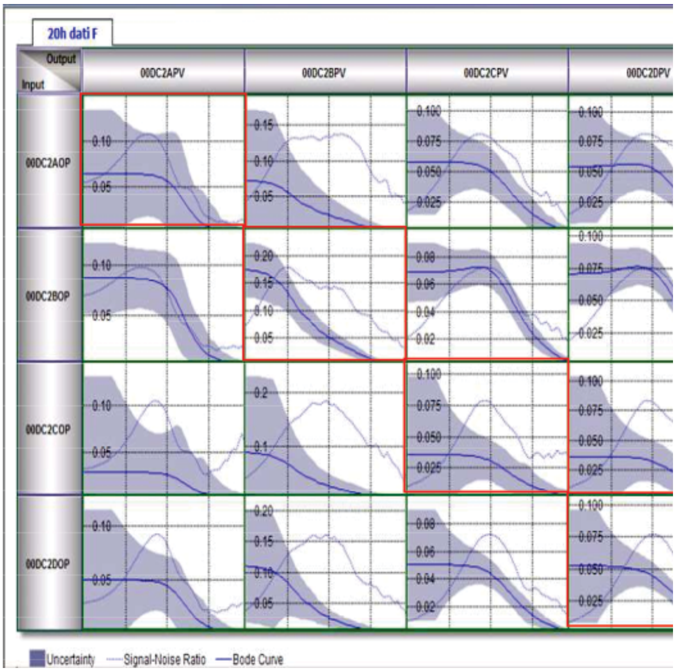
Models can be inspected as either Step Responses or as Bode plots, as shown below for the Hotoil1 controller.

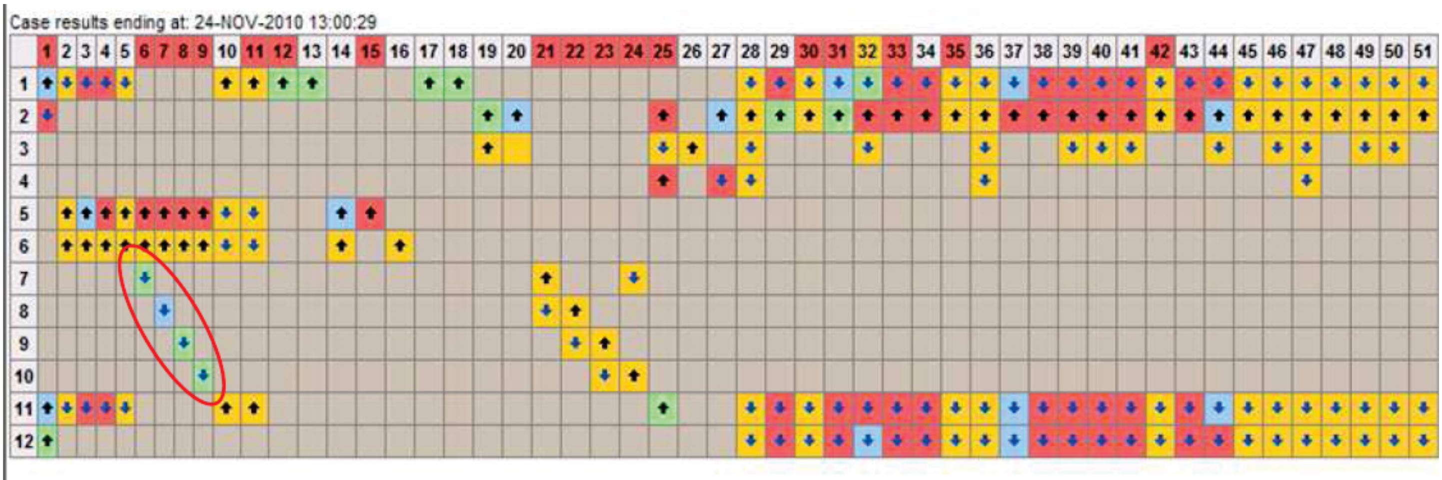


The starting model is shown in blue, while the newly identified model (based on 20 hours of step testing) is shown in pink. Note the substantial differences on the diagonal, exactly where the MQ analysis previously reported model accuracy to be poor.

Bode plots have been actually very useful to monitor modelling progress during step testing. In the 2 pictures below, 3 hours of step test data are compared against nearly 20 hours of step test data, and it can be seen that the uncertainty bands get narrow while the signal to noise ratio improves as the step test proceeds.







The evaluation stopped after 24 hours of unattended step testing, and then the updated models were replaced online from the Web Viewer interface without the need to restart the controller.

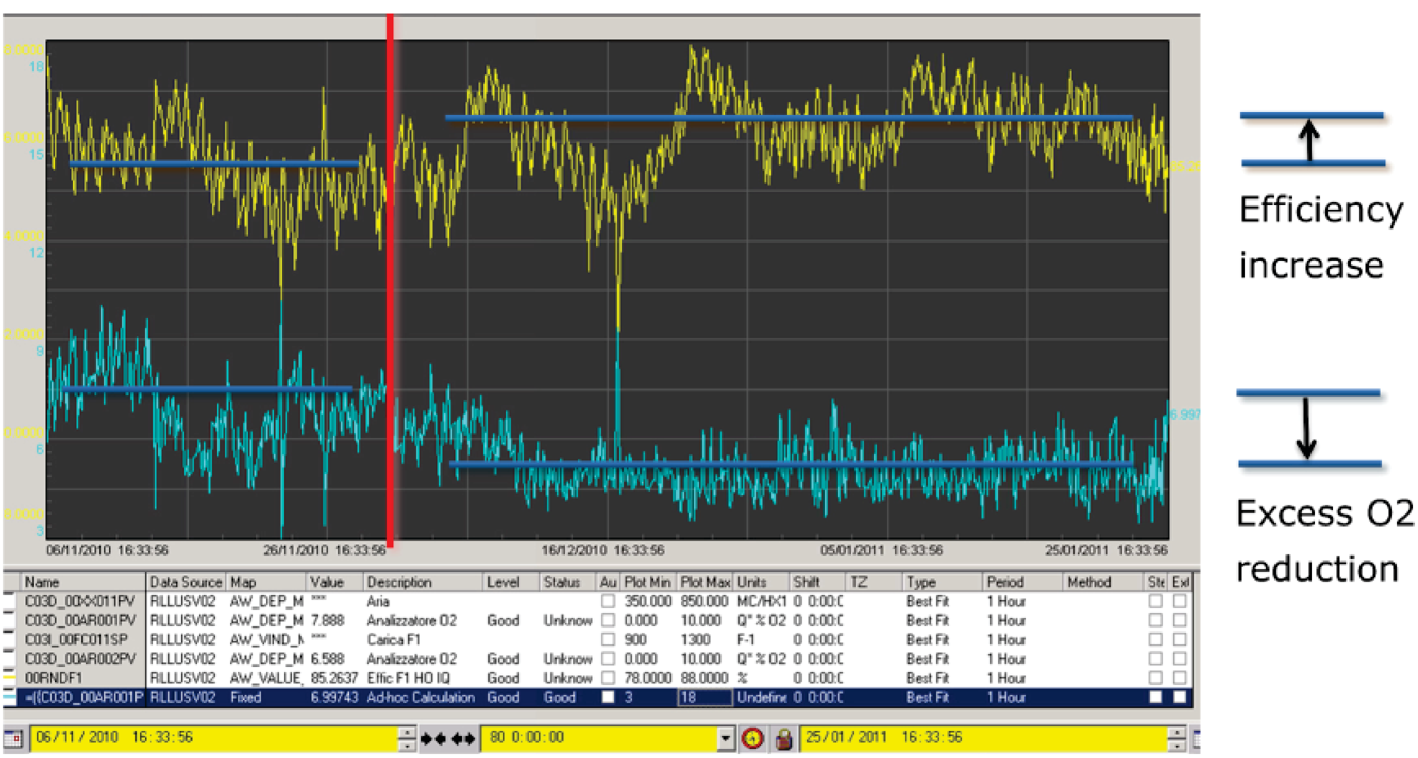
The effect of models and tuning changes can be directly checked on-line through the Production Control Web Server Interface using a What-If Simulation that permits a comparison between old and new responses before deployment.

Model quality was reassessed after deployment to confirm the improvement, as shown above.

Results

The HOTOIL1 controller was brought back into full operation at the end of the evaluation with the following major results:

- Restoring correct operation for HOTOIL1 DMCplus allowed tighter control of excess O_2 and draft in F1 furnace cells.
- The operating target was increased for dampers and decreased for blowers given the new updated models had such good performance.
- Excess O_2 was significantly reduced.
- F1 efficiency increased by 1.2% on average after the revamp and this is significant for a 65 MM Kcal/h furnace in terms of fuels consumption reduction, and worth well above 100000 Euros /year at current fuel oil cost.



The trends above show furnace efficiency and the excess O_2 for 80 days. The evaluation activity is marked with the red vertical bar.

Advantages of the Solution
The entire maintenance process is done on line directly from a web viewer and on the running controller.

It enforces Best Practices and moves maintenance from reactive to proactive, maximizing controller uptime and benefits. Controller performance check-ups becomes a regular activity that requires limited effort.

With the sustained value tools, maintenance activities are triggered by a few properly designed controller KPI's and model KPI's. These KPIs can easily be compared against one or more baselines that can be manually or automatically built in minutes. Automatic reports can be scheduled, designed to include KPI's, calculations and trends, and sent automatically to Operators, Engineers, and Managers (filtered by role).

KPI's carpet plots, diagnostics and drill down capabilities enable the control engineer to rapidly detect and diagnose the problem: instrumentation, DCS PIDs tuning, MPC tuning, MPC design, or MPC models.

Fixing the problem is then mostly automated, while still under engineer control, but with no need for time consuming manual tasks or controller's downtime.

A streamlined APC maintenance process with proper tools is now available to preserve the APC know-how, despite APC engineers moving into other positions.

Proactive maintenance prevents benefits degradation, and almost eliminates the need for costly "full controller" revamping activities, and it also permits the APC engineer to spot new opportunities to increase benefits delivered.

Conclusions
The evaluation performed in ENI R&M Livorno Refinery clearly demonstrated the validity of the methods and tools and here is ENI R&M's assessment:

- HOTOIL1 DMCplus controller section was successfully revamped in just 2 days:
  - *Models were updated and all MVs were put back in service*
  - *This activity delivered immediate and significant benefits (> €100K/year)*
- *The whole process took just 2 days:*
  - *Non-continuous work, as SmartStep took care of plant testing by night*
  - *Adaptive Modeling features helped to speed up the model ID process*
  - *Capability to run Model Quality and Identification from web interface*
- *Adaptive Modeling was evaluated with satisfaction:*
  - *Ranked within ENI R&M circuit as a powerful tool to keep DMCplus controllers efficient over time*
  - *New proactive approach to DMCplus applications maintenance*

We concentrated on just 6 MVs in a furnace (4 dampers and 2 blowers) and it's true that we could have done it manually in the old way, but that would have required several days of continued shift work, and it's very much questionable that the quality of the results would have been the same. In addition, this work can be done by the site APC engineer. There is no need to call on site an external consultant to execute regular maintenance activities, and then avoid this way long delays, and significant cost.

The maintenance activity was completed in around 24 hours with almost no engineering supervision during step testing, and plenty of time to get familiar with the tools and technology, and we had time to discuss what KPI's to put in place, and how to improve controller performance.

This is the key learning: spend the time available to optimize operations and increase benefits and not to execute trivial repetitive tasks.

In a Refinery like ENI R&M Livorno, with many APC applications, even with very good on-stream factors, there are lots of opportunities to improve performance that are not spotted or simply left behind because of the lack of proper tools and methodology, and because there is not enough time to address them working in the old fashioned way.

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