Timely Advanced Control Upgrades: Recapture and Multiply Benefits

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1. Abstract

This paper discusses the establishment of Advanced Process Control (APC) in refining, petrochemical and oil & gas production facilities and the various mechanisms which dictate the lifecycle of an APC application. The benefits of appropriate APC upgrades are examined with the key elements of a variety of case studies highlighted. The case studies cited include an APC technology upgrade and various APC revamps following process context changes (e.g. clean fuels refinery upgrades). The key elements in an APC lifecycle management program are proposed.

2. Current Paradigm

The development of robust Advanced Process Control (APC) technologies, or more specifically Multivariable Predictive Control (MPC) in the late 1980s, has transformed the way operators manage processing units in most oil refineries and petrochemical plants around the world. These software applications, which are effectively a 'cruise control' for the panel operator, have increased plant profitability and allowed the operators to focus on other value added activities which are beyond automation.

Penetration of MPC technologies has been steadily expanding in the last decade with the traditionally conservative oil and gas sector taking on the use of MPC to great advantage: The larger throughputs associated with upstream production are a multiplier on APC benefits which can deliver very impressive paybacks.

The last decade has also seen an increased focus on APC lifecycle management issues as APC applications have their benefits eroded by changes in process context. That is, the APC no longer matches the process needs in terms of plant response, application design or optimiser direction. In some instances, this has caught users by surprise – 'we didn't think that the software would require *maintenance*!'

MPC applications can essentially be broken down into five main elements:

- The generic MPC hardware and software platform which hosts each specific application;
- The MPC Design (or 'structure') refers to the process variables designated as MPC inputs and outputs;

- The Process Model specifies the cause-effect process responses measured between the MPC outputs and inputs;
- The MPC Tuning encompasses the settings of the tuning handles which dictate the control and optimisation performance of the MPC;
- Additional Customisation of the generic MPC technology which is required to meet specific process needs (e.g. DCS custom coding or custom MPC logic which augments the generic MPC functionality).

Each of these five elements is initially matched to the plant needs which may change over time. This in turn can influence whether the MPC remains appropriate and delivers maximum benefit to the plant. These vulnerabilities can greatly erode the APC benefits and require engineering effort to ensure that the value of the investment in APC is sustained.

3. APC Lifecycle Trends

An APC application experiences a lifecycle due to a range of factors which affect whether the application remains fit for purpose:

- The APC application is implemented on a hardware / software platform which will invariably become obsolete in time.
- The design and tuning of the APC is matched to the needs of the process during the initial commissioning and the process needs can change over time;
- The APC sits on top of a regulatory control platform which can deteriorate if adequate instrumentation maintenance is not attended to in a timely manner – this vulnerability is particularly pertinent at sites where there is pressure to reduce maintenance costs and the impact upon production performance is not accurately measured.
- The performance of the APC is affected by the knowledge and expertise of the process operators, APC support engineers and process engineers – regular turnover of personnel can affect APC (and hence plant) performance.

APC Computer Platform Issues

In the case of the hardware or software platform becoming obsolete, outdated or unsupported the decision to upgrade the APC platform is relatively simple (and no different to a range of other business systems). This decision generally results from information broadcast by hardware and technology vendors. Typically, hardware and software upgrades are relatively trivial exercises whereas software technology conversions can be much more involved due to the need to convert the process model and deliver similar performance with a potentially dissimilar control engine and tuning handles.

Process Context Changes

The onset of APC benefit losses due to a change in process needs can be more difficult to identify as the losses can be quite subtle initially and the ongoing erosion can be slow. Furthermore, changes in process context can materialize in a variety of ways with different levels of impact upon APC benefits, such as:

- Changes in feedstock flow and/or throughput can impact the plant cause-effect responses and result in model mismatch within the APC;
- A major change in process operating conditions can also impact the plant cause-effect responses and result in model mismatch within the APC (e.g. a significant change in product quality specifications);
- Similar process changes can introduce a new process constraint which should be honoured and is not included in the existing APC design. This can result in heavy benefit losses due to the process being over-constrained to protect these limits;
- Deterioration in regulatory control performance (e.g. blocked impulse line or valve stiction) results in increased process noise and prompts operators to increase margins from true process constraints with a loss of APC benefits. In the extreme case, faulty instrumentation can force the APC to be switched off completely.

The robustness of each individual APC application to changes in process context is specific to the nature of the control problem, the inherent robustness of the technology employed and the quality of the APC design. For example, with regard to MPC technologies, some are less robust to model error than others whilst some are adaptive in their nature. Similarly, application design can greatly influence response to model error and/or an application's likely exposure to model error.

Human Factors

As per Process Context changes, the influence of Human Factors can be quite subtle and difficult to detect until substantial performance degradation is experienced. Furthermore, the issue of lifecycle management is hampered by the fact that use of the technology is still relatively new and that some of the lifecycle mechanisms involved are typically longer than many job rotations. This in turn can result in the some complications:

- Site management (and the wider organisation) may not appreciate the value of APC if it was implemented before their tenure or a thorough post audit was not conducted – this can affect the priority given to any APC maintenance work;
- Process control support engineers may not have the experience or mandate (time) to implement the required maintenance;
- Brisk job rotations can leave little opportunity for process control engineers to develop the skills necessary to tackle APC maintenance needs. For example, engineers may not have the background to confidently 'look under the bonnet at the engine' of a sick application if they have not been involved in an APC development project.
- Turnover of operations personnel may result in loss of expertise and result in misuse of the APC application such that benefits and/or operator support are lost. In this case, the maintenance required may simply be appropriate refresher training for operators.

Mismanagement of APC lifecycle needs can erode confidence in the technology and results in cycles in APC popularity which represent significant benefit giveaway. For example, Process Control Managers with good understanding of the technology will progress timely APC maintenance work whereas others may let the APC performance deteriorate to the point that it is permanently switched off.

Figure 1 below depicts the expected flow of costs and benefits for a typical APC application over time with no APC maintenance support (i.e. the worst case scenario). Note that the net cashflow to the user is the sum of the costs and benefits (these are shown separately to clearly illustrate the contribution of each).

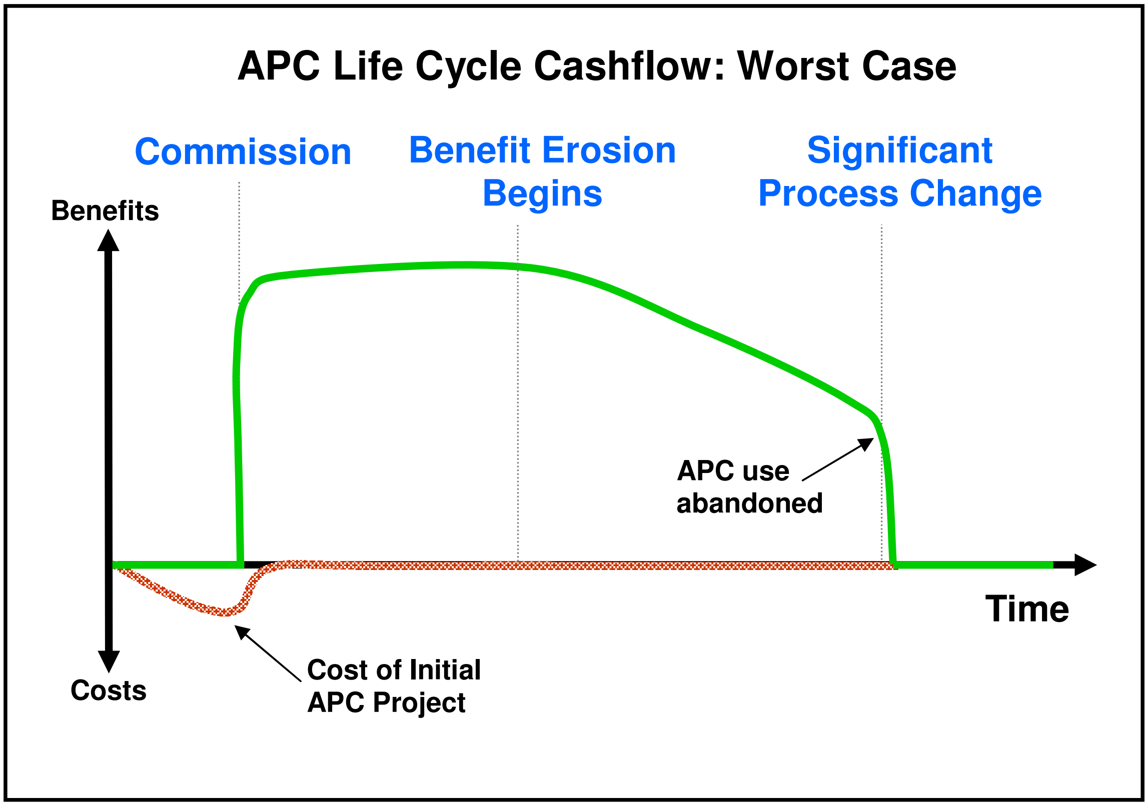

Figure 1 – The Worst Case Scenario Cashflow with no APC Maintenance

Positive Lifecycle Mechanisms

Not all APC lifecycle trends are negative to the application benefits. As a new APC application can often change the operating point of the process substantially, there is often some iterative optimisation of the use of the new tool which over time delivers improved benefits.

Some examples of positive lifecycle developments include:

- Monitoring of the APC constraints coupled with an active constraint busting effort by engineers and operators results in mechanical modifications to relieve plant constraints and improve profitability (e.g. the trim is increased in a limiting control valve);
- The APC provides a new way of using the available degrees of freedom and optimal use of this new 'steering wheel' can take some time to develop – this assumes that the site process engineers, control engineers and operators are motivated to extract full value from the new APC after the initial commissioning period. For example, there are a number of ways to affect bed temperature profile control in a multi-bed reactor;
- Changes in process context can relieve (or make redundant) process constraints and allow improved plant profitability;
- Some APC applications are coupled with custom sequence logic to help manage discrete events (e.g. plant mode changes for different production runs). Often the sequence logic can be optimised via analysis of multiple instances with respect to the process objectives (e.g. minimising transition time, minimising product specification giveaway etc).

Although many optimisation activities are most relevant soon after the APC commissioning, there is great value in an ongoing application optimisation focus.

4. The Value of APC Revamping

Occasionally process changes leave the application design or process model significantly mismatched to the process needs and a thorough *revamp* of the APC application using a focused engineering team is required. The bulk of the engineering effort involved is associated with the redevelopment of the process model and the application re-commissioning. As the time required to review the design is relatively minor, it is a good idea to add this activity to the revamp scope of work to ensure that any opportunity to increase the APC benefits is exploited (i.e. even if model mismatch is the only obvious initial driver for the revamp activity).

Cost of APC Revamping

In contrast to the original APC application development, the cost of revamping can be a fraction of the original development due to a range of factors:

- The required hardware and software platform already exists and is proven;
- The operators are familiar with the use of APC technology and already understand how a APC application will control the process – this often results in a major reduction in operator training needs and an improvement in operator ownership and design input;
- The design evolution associated with a revamp often involves a reduction in the size of the application (as new builds typically include variables which 'may come in handy' as the use of the new tool develops) – this can often reduce the cost of remodeling, recommissioning and training on the new APC application;

- Depending upon the degree to which the APC design changes from the original application, the cost of remodeling can be further reduced by using the newer automated techniques for step testing which rely on a datum model as a starting point (that is, the old model can be used to seed the remodeling effort).

Benefits of APC Revamping

Typically, revamping is initiated on the premise of recapturing benefits lost from the original APC application. Often further benefits can be realised with some examples being:

- APC design evolution can deliver significant improvement in benefits as the operating history of the current APC application can provide skilled APC designers with ideas for:
  - Enhanced use of available degrees of freedom to meet process needs (i.e. improved design of the APC *steering wheel*);
  - Addition to the scope of the application to increase the breadth of APC benefits;
  - Improved integration with other APC and/or higher level optimisation applications;
  - Removal of redundant variables to keep the application intuitive and user friendly (thereby maintaining operator expertise more easily).
- Elevated levels of operator expertise can result following additional APC training during the APC re-commissioning. As the operator understanding of the APC is already developed, training sessions are more often two-way discussions focusing on more advanced concepts and optimal use of the APC.
- A focused effort on improving the performance of the APC can provide the impetus to fix deficiencies in the regulatory control which have been deferred due to the priority of minimising maintenance costs over eliminating poorly defined production losses. Often these instrumentation issues are difficult to resolve with the low priority given to faults identified by weekly APC maintenance activities.
- If the benefits of the revamp meet expectations and are appropriately communicated, a well managed revamp can reinvigorate the appreciation of the value of APC in the entire organisation. This can be particularly important for operating plants where APC applications have been online for a number of years and their role in delivering the site profitability has been largely forgotten.

Thus appropriate APC revamps can deliver impressive paybacks relative to the original APC project and allow the APC applications to reach a higher datum of value to the plant. Revamps are also an important activity for sustaining the effectiveness and expertise level of the site support team by providing opportunities for concentrated review of application designs (and if external consultants are engaged, more opportunities to work with APC experts).

Figure 2 depicts a more attractive APC lifecycle cashflow which results from an ongoing APC maintenance focus incorporating revamps when appropriate. The increased flow of APC benefits should greatly outweigh the cost of the increased engineering support.

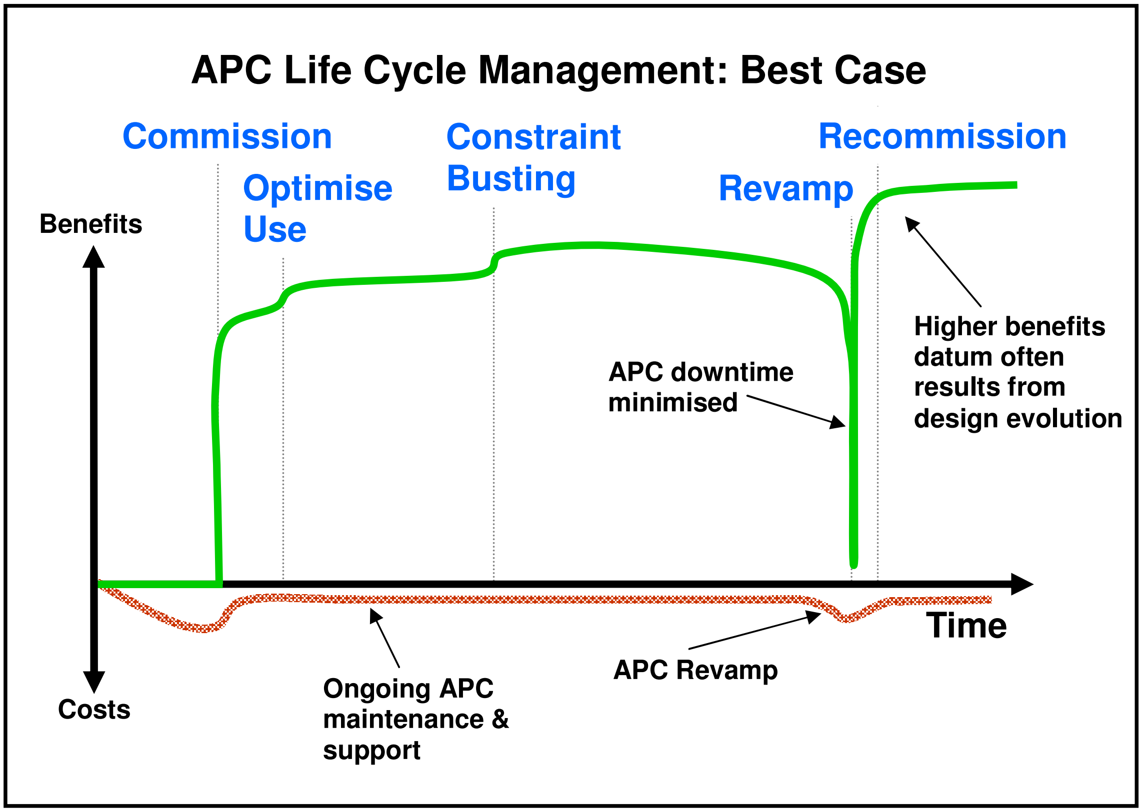

Figure 2 – The Best Case Scenario Cashflow with Appropriate APC Maintenance

5. Case Studies

The following case studies highlight some key aspects of recent MPC upgrade projects undertaken by ProSys Engineering and the value delivered.

Brisbane Oil Refinery SMCA to DMC+ Migration

An oil refinery in Brisbane, Australia, which has been a strong subscriber to MPC technology for over a decade, sought external expertise to help with a major upgrade. In March 2004, the refinery engaged ProSys Engineering to assist with conversion of a suite of 18 SMCA controllers to the latest DMC+ technology. The primary driver for this project was a move away from the unsupported Vax 4505A hardware platform to the current Windows operating system (the change in MPC technology was necessitated by the upgrade in hardware). To this end, the project was considered a "Stay in Business" requirement to ensure that the reliability of the MPC benefits was maintained. As such, it was a difficult decision for the refinery to make as failure statistics for the 4505A machines was hard to source and the premise was that of minimising losses as opposed to any clear profit opportunity.

The scope of work involved upgrade of the SMCA controllers to deliver like-for-like functionality in the new DMC+ format. Although the process model of the SMCA controllers were maintained, the DMC+ tuning handles and optimiser configuration are different from SMCA and this required some translation using engineering judgment and analysis of simulation runs to assess relative performance. Combined with the requirement to develop a generic DMC+ operator training package, groom the SMCA process model for DMC+ use, combine external constraint override schemes on some Manipulated Variables into additional Controlled Variables and perform thorough Factory Acceptance Testing, the migration process for each application was not trivial. The conversion process started with the two crude units to protect the larger benefit producing MPCs at the earliest opportunity.

The project team's familiarity with the DMC+ software encouraged exploitation of the enhanced MPC features to the benefit of the plant performance. More specifically, correct use of the prediction error filter and optimiser functionality provided greater robustness to model error and improved plant profitability.

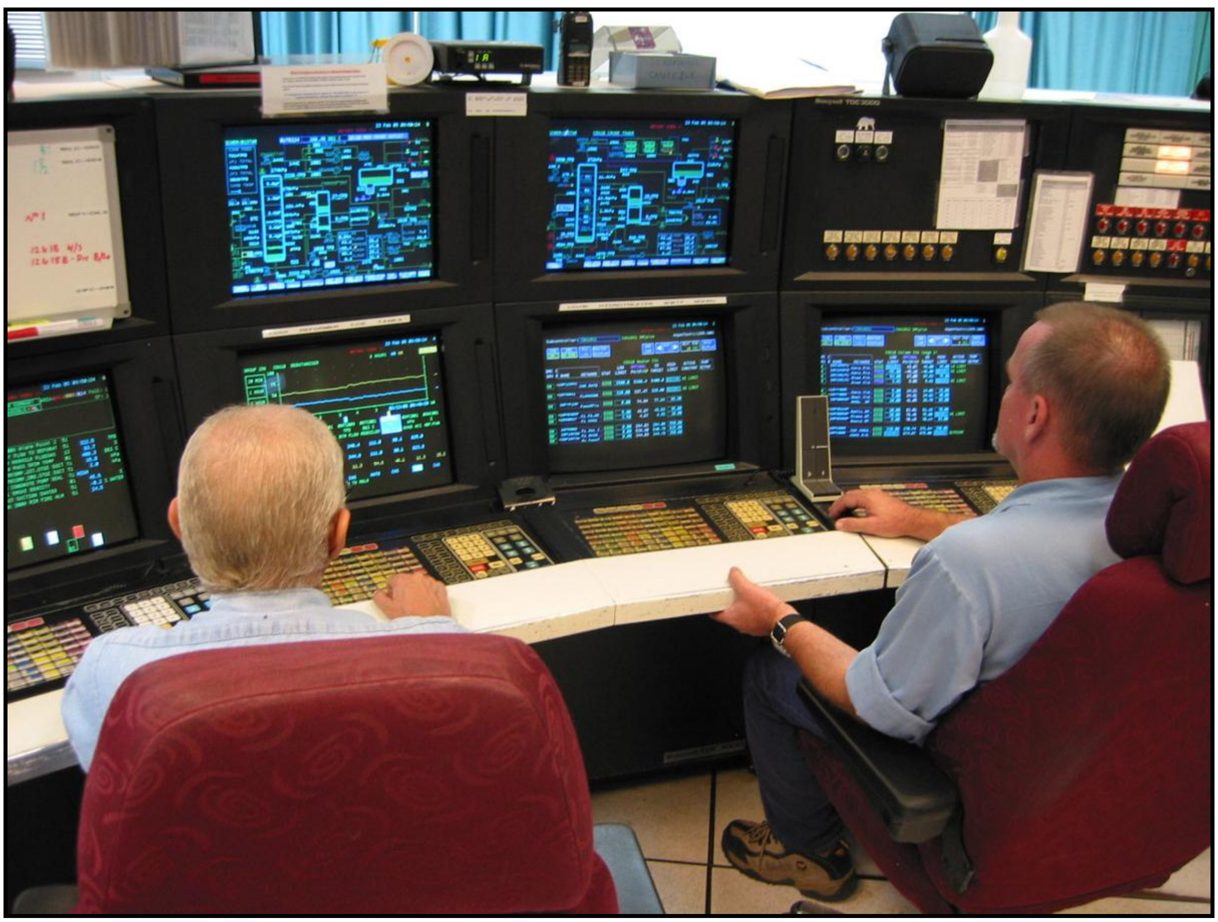

Figure 3 – Panel Operators using the new APC system in Brisbane, Australia.

As the process models used by the SMCA controllers were relatively old, there were some issues detected during the conversion activities which suggested a loss of MPC performance due to model error. The prediction error filter functionality of DMC+ was (at the time) a relatively recent development which greatly improved the controller stability in the face of model error. Judicious use of this robustness feature enabled the project team to extend the life of the process models and deliver improved process performance with the new DMC+ platform.

The new DMC+ optimiser functionality (the superseded SMCA applications worked with a system of Ideal Resting Values and relative importance), allowed the project team to improve the yields from the two Crude units and deliver an annual economic benefit to the site which paid for the entire conversion project. This effectively turned what was a risk motivated project into a handsome profit improvement exercise.

Oil Refinery MPC Revamps

An oil refiner with a strong history of MPC use and well developed culture of APC maintenance has engaged ProSys Engineering to help resolve resource pinch when experienced APC engineering support was required. Two of the MPC revamps undertaken are cited to illustrate the unique value delivered by the projects.

Vacuum Distillation Unit MPC Revamp

The refinery was preparing to adopt a significant change in Vacuum Distillation Unit (VDU) yield structure to meet a change in lube oil basestock specifications and the sustained operation of the MPC was in doubt. Accordingly, a MPC revamp was scheduled for the earliest opportunity after the product regime change.

The project employed a hybrid team of ProSys Engineering and customer engineers and was fast tracked with a two month schedule. The project results surpassed expectations with the key results being:

- A project payback of < 4 months based solely on a quantified reduction in slop cut production;
- Improved combined distillate yield;
- Much reduced variance in distillate viscosities;
- Improved protection of stripper level control when yield maximisation had previously resulted in loss of draw tray levels. An example of this was observed during commissioning when the new MPC was switched on during a loss of stripper level control and it continued to increase the draw flow whilst correcting the loss of stripper level by adjusting the column heat balance.

Crude Unit MPC Revamp

Following the Clean Fuels upgrades of refinery units in late 2005, significant changes to the configuration of the crude distillation complex rendered the existing MPC application redundant. A MPC revamp was initiated to recapture the lost benefits at the earliest opportunity.

The MPC revamp was expedited by using an automated step testing technique using the old process model as a basis. The MPC remodeling effort and recommissioning were combined into a single month long campaign to fast track the project. The result for the refinery was the prompt return of an appropriate MPC application and the associated benefits.

Woodside Energy NW Australia MPC Revamps

Woodside Energy Limited operates the LNG production complex on the Burrup Peninsula in North Western Australia and distinguishes itself relative to its peers in the Oil and Gas industry with the relatively early uptake of MPC technology. The first MPC applications were commissioned a decade ago and the impressive economic and operability benefits realised by the site have supported the development of a site process control support group and a focus on maintaining APC performance. Two of the MPC revamp projects undertaken by ProSys Engineering with Woodside over the last five years are of particular interest as they clearly highlight some of the benefits achievable.

Domestic Gas Plant MPC Revamp

The Domestic Gas Plant consists of two trains, each comprising two inlet separators, a Deethaniser column with an expander/recompressor set and two export compressors. Following the initial MPC commissioning in 1999, an increase in plant throughput (of approximately 25%) combined with rewheeling of some of the key rotating equipment resulted in some noticeable loss of MPC performance. This prompted the MPC revamp in 2003.

The project team conducted a design review prior to remodeling the MPC and this resulted in some major design changes which greatly improved the benefits delivered. Some of the key enhancements involved were:

- Changing the C2% in propane constraint from two individual train constraints to a single combined product quality constraint to gain a degree of freedom;
- Adding functionality to improve turbo expander utilisation and reduce usage of the JT valve – this greatly improved Deethaniser LPG extraction efficiency;
- Addition of functionality to reduce sales gas LPG quality giveaway according to the daily quality specifications;
- Improvements to the regulatory control below the MPC to simplify the MPC structure and improve the linearity of the system (i.e. improve the regulatory control design for use by the linear MPC technology employed).

The results of the revamp project exceeded expectations with Woodside highlighting a number of positive aspects in the post audit report:

- The increase in LPG extraction was 2.5 times that expected with 70% of the measured benefits from the revamp being attributed to improved MPC design;
- The project payback was less than one month (on schedule and within budget);

- Operator expertise was greatly developed as a result of the project activities;
- Improved understanding amongst the engineers of the process characteristics and control technology employed.

LPG Fractionation Plant MPC Revamp

The LPG Fractionation plant consists of two trains, each comprising of Deethaniser, Depropaniser and Debutaniser columns with a single feed drum supplying both trains. Since the seven original MPC applications were commissioned on the unit in 1997, increases in throughput had resulted in substantial model error and resulted in column capacity constraints being experienced. Woodside recognised that the addition of the 4th LNG train in late 2004 was going to push the capacity of the LPG Fractionation plant further and every drop of throughput impacted the bottom line for the site significantly. As a result, a MPC revamp was initiated in 2004.

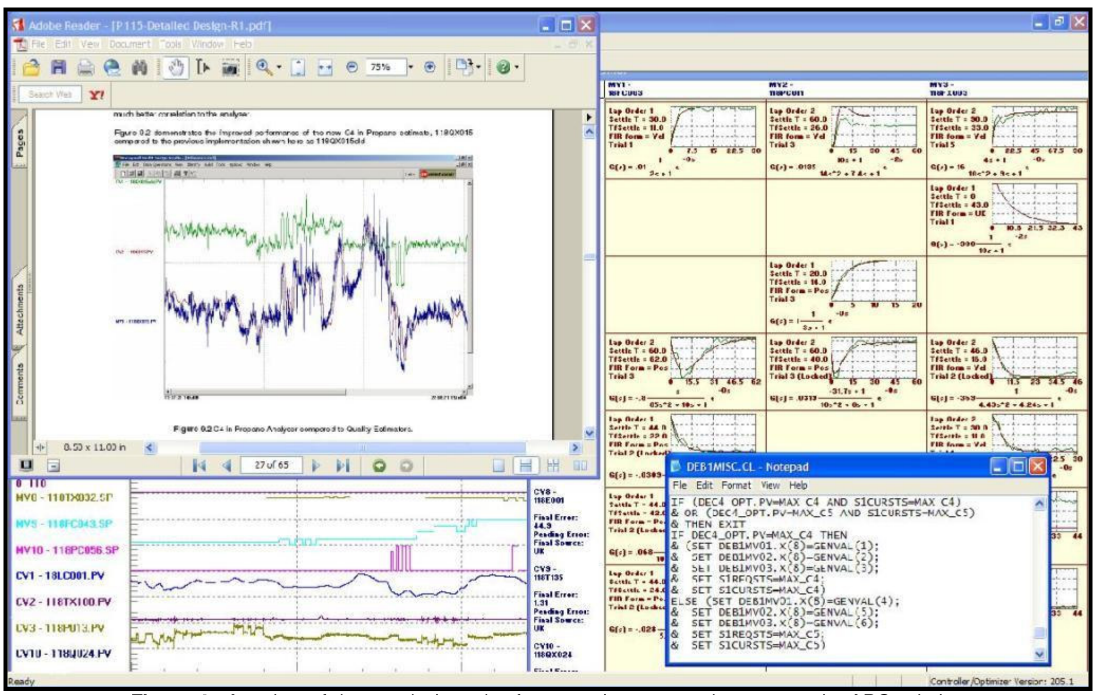

Figure 4 - A variety of data analysis and software tools were used to revamp the APC solution

The project team completed a design review with the new process context in mind. The important design changes included:

- Combination of the upstream five applications (i.e. feed drum, two Deethanisers and two Depropanisers) into a single application to improve process optimisation between the limiting sections of the two trains;
- Redesign of the way that Deethaniser column flooding was managed to ensure that maximum capacity was consistently achieved;
- Reformulating the individual column product quality constraints as combined quality constraints to provide an additional degree of freedom. This was particularly useful during

discrete refrigerant production runs off one Depropaniser when very high purity propane product could be diluted with low purity propane to maximise overall product yields.

Again, the results of the revamp exceeded expectations with the main benefit being an increase in unit capacity of over 10% - this delivered a significant improvement in profitability for the site for a relatively trivial investment. Operator feedback was also very positive following rationalisation of the application designs and further refresher training during the project execution.

The results of these case studies demonstrate how judicious revamping by experienced APC practitioners can greatly add to the evolution of APC applications and the value delivered to the plant owners.

6. Suggested Elements of a APC Lifecycle Management Program

To support the APC lifecycle needs and maximise the process benefits, there are four main activities which site personnel need to manage:

- **APC Usage Optimisation** – this involves leadership of the positive lifecycle mechanisms such that APC benefits are improved whenever possible.

  Weekly review of the process context and APC performance can highlight opportunities to improve the APC benefit datum. Optimisation activities are likely to most prevalent immediately after initial commissioning or following changes in process context. Success of this activity relies upon close communications between planning, process and control personnel;

- **APC Maintenance** – this work includes minor changes, such as application tuning adjustments, custom logic modifications and improvements to process submodels, to maintain the APC performance at the accepted datum. Ensuring that a high level of operator expertise and process engineer understanding is maintained is also part of the maintenance function.

  A daily to weekly review of APC performance can help ensure that performance datums are maintained. The exact frequency for each application will depend upon the relative APC benefits, availability of site support engineers and the susceptibility of each application to benefits erosion. Some maintenance activities can be promptly completed (e.g. minor tuning changes), whereas others (e.g. remodeling specific submodels) can involve significant planning, engineering effort and communication;

- **APC Revamp** – this involves a complete remodeling exercise to bring the APC model in line with the current process operation and may be instigated by wide spread model error or deficiencies in the APC design. The opportunity to review the APC design should always be taken as it represents minimal additional cost and can deliver significant additional value. The revamped application needs to be recommissioned with particular focus on any functional changes.

Revamps should be initiated when process context changes are significant enough to cause substantial loss of APC benefits. As major changes in process context are usually caused by capital projects, the need for these revamps should be predictable (and indeed, the cost of these revamps should be borne by the capital project if the APC is accepted as an integral part of the plant HMI). In the case where proactive planning has not been completed (significant APC benefit loss is already being sustained), regular APC maintenance activities which cannot resolve heavy APC benefit loss should highlight the need for application revamp. In most oil refineries, changes in process context (e.g. clean fuels modifications and debottlenecking) lead to the need for application revamps approximately every 5 years whereas more stable operating environments can sustain good APC performance for over a decade;

- **APC Technology Upgrades** – the improved benefits of new technologies or the lack of support for outdated technologies can precipitate the need for a technology migration. Depending upon the specific context, this is done as a straight conversion (maintaining the existing process model) to minimise transfer time or combined with a Revamp to leverage the engineering focus already being applied to each application.

  Technology upgrades will generally be prompted following advice on technology roadmaps from software vendors. Upgrades within a specific brand of APC technology are typically trivial exercises which may be warranted every few years (it is often prudent to avoid the 'bleeding edge' of new technology and let others discover any new bugs). Given that the rate of technology development is relatively slow in this niche market and the differences between competing products are subtle, technology migrations are rare events (usually prompted by resolution of value 'holes' in older technologies or changes to corporate agreements).

Automated Monitoring Tools

To assist with the monitoring activities required to support APC Maintenance activities, most technology vendors have developed (or are developing) automated monitoring packages to allow support engineers to quickly assess the health of an APC application using historian data. If properly configured (i.e. KPIs are correctly oriented at the important performance metrics), an APC monitoring system can reduce the burden of APC monitoring and help maintain performance expectations throughout the application lifecycle.

Similarly, automated monitoring packages to assess regulatory control performance are also available. Although these products have been available for a number of years, the uptake of condition monitoring for regulatory control loops has not been as great as expected (unlike the use of condition monitoring for rotating equipment which is now widely accepted). This is perhaps because, unlike rotating equipment, it is still possible to run the plant with most regulatory control in manual mode (albeit poorly) and complete failures rarely result in a total loss of production. That is, the '*battle between hidden costs and visible costs*' is prevalent in most operating plants and there is significant value lost (but not measured) by deferring maintenance work on regulatory control instrumentation.

Both automated monitoring of regulatory control and APC are futile activities unless there is commitment to act on the results of the monitoring. That is, these packages are efficiency tools which don't resolve the need for maintenance – they simply help define where scarce maintenance resources should be best directed.

Elements of Success

Some key *Elements of Success* required to ensure that the APC Lifecycle Management Program delivers maximum value include:

- Open and close communications between the planning, engineering and operations groups on process objectives and forward plans. As the APC seeks to optimise the plant operation, control support engineers need to be aware of accepted changes in plant objectives which need to be matched by the APC.
- Clear understanding and acceptance of the value of APC to the bottom line is required to ensure buy-in from all stakeholders. Often a simple and well broadcast post audit of the initial benefits realised is adequate to ensure alignment throughout the organisation. Process engineers need to understand the value of the APC and use it as a tool to deliver the process optimisation that they wish to achieve.
- Clear mandate for control engineers to undertake the required lifecycle management activities when required. The basis of all the key activities is monitoring of plant performance and APC operation on a suitable frequency. The development of APC monitoring tools has been slow with some major developments in recent years. Even without these efficiency tools, effective monitoring can be affected via analysis of historian trends of key variables. Often a brief trip to the control room for a discussion with the panel operator can yield a lot of valuable information (and this helps to reinforce positive support relationships between operators and control support engineers).
- Commitment to timely resolution of instrument maintenance needs which impact upon APC benefits (and left unchecked will result in complete instrument / APC failures).
- Commitment from management to training and stability of control engineering support is required to ensure that skilled personnel are available to undertake support activities. The complexity of some APC applications requires a high level of engineering expertise and additional operating training support to sustain the benefits delivered. Whereas a chemical

engineer may immediately deliver peak results in a process engineering role, it can take 1-2 years for the same engineer to develop all the skills and experience required to operate at the same level in a process control role.

- Access to external expertise to augment site resources when required. Typically, site support teams are manned for application maintenance activities but not the heavy project work loads demanded by Revamps and Technology Upgrades. Often the depth of experience offered by external consultants is particularly useful for design review, remodeling and commissioning activities in addition to understanding the finer points of applying APC technology.

7. Summary

The advent of modern APC technologies has delivered significant automation and process optimisation value to the hydrocarbon processing industries. Whereas some APC users are aware of the vulnerabilities and opportunities relating to the sustained delivery of APC benefits and act to address these needs, many are not. Failure to recognise the lifecycle needs of APC applications can accelerate benefits erosion and precipitate a cycle in popularity of the technology – this represents significant loss of value to the plant by foregoing a relatively minor investment.

The case studies presented clearly illustrate the value of appropriate APC upgrades and demonstrate a pattern of these projects exceeding expectations. This demonstrates that a strategy of APC evolution leveraging external consultants can produce very positive results with highly desirable project economics.

The lifecycle management framework proposed is a basis for addressing typical APC vulnerabilities and opportunities for improvement. The exact approach which best meets the needs of each site is a function of local characteristics and the management objectives with regard to APC. A culture of continuous optimisation in every aspect of the plant operation, including exploitation of Advanced Control technologies and application evolution, will ensure that profitability of the site is maximised.