Advanced Process Control Implementation Guide

PTS 20.00.20.39

DEC 2008
This new PTS 20.00.20.39 – Advanced Process Control Implementation Guide has been developed to provide a standard guideline for implementing Advanced Process Control applications, specifically Multivariable Predictive Controllers and Inferential Quality Estimators in PETRONAS operating units. It is intended for use by PETRONAS and Vendor when preparing to embark on an Advanced Process Control project in the plants and also during the operation and maintenance of the system.

This PTS also includes PETRONAS Lessons Learnt and PETRONAS Best Practice for the subject matter Advanced Process Control Implementation Guide.

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<th>Document Approval</th>
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1 INTRODUCTION

1.1 OBJECTIVE

The objective of this document is to provide a standard guideline for implementing Advanced Process Control applications, specifically Multivariable Predictive Controllers and Inferential Quality Estimators in PETRONAS operating units. It is intended for use by PETRONAS and Vendor when preparing to embark on an Advanced Process Control project in the plants and also during the operation and maintenance of the system.

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Unless otherwise authorised by PETRONAS, the distribution of this document is confined to companies forming part of or managed by PETRONAS, and to Contractors and Manufacturers/Suppliers nominated by them.

This PTS is intended for use in oil refineries, gas plants, chemical plants and, where applicable, in exploration and production facilities and supply/marketing installations. If national and/or local regulations exist in which some of the requirements may be more stringent than in this PTS, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this PTS which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the authorities concerned with the object of obtaining agreement to follow this PTS as closely as possible.

1.3 DEFINITIONS

1.3.1 General Definitions

The Contractor is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The Manufacturer/Supplier/Vendor is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The Principal is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word “shall” indicates a requirement.

The word “should” indicates a recommendation.

1.3.2 Specific Definitions

Manipulated Variables (MV)
Independent variables that are manipulated to achieve desired results, typically in a controlled variable. This may be in the form of a setpoint to a control loop or may be an output sent directly to a control valve.
Controlled Variables (CV)
Dependent variables that are to be controlled to targets and/or keep within constrained limits.

Disturbance Variables (DV) or Feed Forward Variables (FF)
Independent variables (measurable) that affect the process which are not manipulated in the controller.

Time to steady state (TTSS)
Time taken for the process to settle after a change in an independent variable.

Multivariable Predictive Controller (MPC)
An MPC manipulates several setpoints and/or valve positions simultaneously to achieve its control objectives. It employs a model predictor containing dynamic models of the process and predicts the process behavior and responds accordingly.

1.3.3 Abbreviations

MPC  Multivariable Predictive Controller
MV   Manipulated Variable
CV   Controlled Variable
DV   Disturbance Variable
APC  Advanced Process Control
QE   Quality Estimator
PFD  Process Flow Diagram
P & ID Piping and Instrumentation Diagram
DCS  Distributed Control System
FAT  Factory Acceptance Test
SAT  Site Acceptance Test
FCCU Fluid Catalytic Cracking Unit
PVO  Product Value Optimisation
RVP  Reid Vapour Pressure
SPC  Statistical Process Control
FF   Feedforward
IRC  Intermediate Regulatory Control
ARC  Advanced Regulatory Control

1.4 PROCESS UNDERSTANDING

The backbone of any successful MPC applications is clear understanding of the process. This is necessary in order to develop a good representation of the process and formulate plant step test strategy. The process knowledge should be obtained by
- in-depth discussion with technologists, operations, production/economic planners and instrument personnel
- reference to similar plant/process technology
- reference to design books, PFDs, P&IDs, DCS schematics and controller narratives documentation
- running process steady-state simulator of the plant, if available

Refer to Appendix A for salient points to be considered.

1.5 TECHNOLOGY UTILISATION IN PETRONAS

There are many APC providers in the market and most are comparable with one another. Two APC providers shall be utilised, i.e.
i. Honeywell
   Profit Controller / Robust Multivariable Predictive Control Technology (RMPCT)

ii. Yokogawa
   Shell Multivariable Optimising Controller (ExaSMOC)

Exceptions apply to specialised applications, such as in highly non-linear processes.

The following is the list of sites in PETRONAS that has APC applications installed:

<table>
<thead>
<tr>
<th>Operating Unit</th>
<th>APC Provider</th>
</tr>
</thead>
<tbody>
<tr>
<td>PETRONAS Penapisan Melaka Sdn. Bhd</td>
<td>Honeywell</td>
</tr>
<tr>
<td>PETRONAS Penapisan Terengganu Sdn. Bhd</td>
<td>Honeywell</td>
</tr>
<tr>
<td>Malaysia LNG Sdn. Bhd. (1, 2 and 3)</td>
<td>Yokogawa</td>
</tr>
<tr>
<td>Petronas Gas Bhd.</td>
<td>Yokogawa</td>
</tr>
<tr>
<td>MTBE Sdn. Bhd.</td>
<td>Invensys, Axens, Dow</td>
</tr>
<tr>
<td>Ethylene Malaysia Sdn. Bhd.</td>
<td>AspenTech</td>
</tr>
</tbody>
</table>

2 PERSONNEL INVOLVEMENT FROM SITE

An APC project requires involvement from APC engineers, production/economic planners, operations, process technologists, instrumentation/systems engineers and others. They may not be involved full-time at a certain phase but their input is crucial for the success of the project.

The following table lists the typical roles and responsibilities during each project phase:

<table>
<thead>
<tr>
<th>Project Phase</th>
<th>Main Responsibility</th>
<th>Supporting Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility studies</td>
<td>Experienced APC leader and/or 3rd party consultant</td>
<td>APC engineer, production/economic planner, operations, process technologists, instrumentation/systems engineer</td>
</tr>
<tr>
<td>Controller basic design</td>
<td>APC leader and/or 3rd party consultant</td>
<td>APC engineer, production/economic planner, operations, process technologists</td>
</tr>
<tr>
<td>Base layer performance review and improvement work</td>
<td>APC engineer, instrumentation/systems engineer</td>
<td>APC leader, operations, field technician, 3rd party consultant, process technologists</td>
</tr>
<tr>
<td>Inferential model building (if any) or validation</td>
<td>APC engineer</td>
<td>APC leader, 3rd party consultant</td>
</tr>
<tr>
<td>Plant pre-test</td>
<td>APC leader, APC engineer, operations, 3rd party consultant</td>
<td>Field technician, instrumentation/systems engineer, production/economic planner</td>
</tr>
<tr>
<td>Final controller design</td>
<td>APC leader and/or 3rd party consultant</td>
<td>APC engineer, production/economic planner, operations, process technologists</td>
</tr>
<tr>
<td>Plant step test</td>
<td>APC leader, APC engineer, operations</td>
<td>3rd party consultant, operations, instrumentation/systems engineer</td>
</tr>
<tr>
<td>Dynamic model identification</td>
<td>APC engineer</td>
<td>APC leader and/or 3rd party consultant</td>
</tr>
</tbody>
</table>
### Dynamic model review (during FAT)
<table>
<thead>
<tr>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>APC leader, APC engineer, operations</td>
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</tbody>
</table>

### Controller building
<table>
<thead>
<tr>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>APC engineer</td>
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</tbody>
</table>

### Off-line simulation and tuning (during FAT)
<table>
<thead>
<tr>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>APC leader and/or 3rd party consultant</td>
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</table>

### On-line installation and tuning
<table>
<thead>
<tr>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>APC leader and/or 3rd party consultant, instrumentation/systems engineer</td>
</tr>
</tbody>
</table>

### Operator training
<table>
<thead>
<tr>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>APC leader and/or 3rd party consultant</td>
</tr>
</tbody>
</table>

### Performance test run / Project wrap-up / post commissioning review (SAT)
<table>
<thead>
<tr>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>APC leader, APC engineer and/or 3rd party consultant</td>
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</table>

### Process technologists involvement is typically as follows:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility studies</td>
<td>Feedback on process operations, constraints</td>
</tr>
<tr>
<td>Controller basic design</td>
<td>Selection of MVs, CVs and DVs</td>
</tr>
<tr>
<td>Base layer performance review and improvement work</td>
<td>Feedback on controller performance</td>
</tr>
<tr>
<td>Plant pre-test</td>
<td>Recommend step size, make step changes and monitor plant</td>
</tr>
<tr>
<td>Final controller design</td>
<td>Finalise selection of MVs, CVs and DVs</td>
</tr>
<tr>
<td>Plant step test</td>
<td>Recommend step size, make step changes and monitor plant</td>
</tr>
<tr>
<td>Dynamic model review (during FAT)</td>
<td>Verify model against actual plant behaviour</td>
</tr>
<tr>
<td>Off-line simulation and tuning (during FAT)</td>
<td>Verify control action against normal operating practise</td>
</tr>
<tr>
<td>Operator training</td>
<td>Full attendance and understanding of operating with APC</td>
</tr>
<tr>
<td>Performance test run / Project wrap-up / post commissioning review (SAT)</td>
<td>Monitor and feedback on controller performance</td>
</tr>
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### Operations roles during the following stages are:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility studies</td>
<td>Feedback on process operations, constraints</td>
</tr>
<tr>
<td>Controller basic design</td>
<td>Selection of MVs, CVs and DVs</td>
</tr>
<tr>
<td>Base layer performance review and improvement work</td>
<td>Feedback on controller performance and provide control philosophy</td>
</tr>
<tr>
<td>Final controller design</td>
<td>Finalise selection of MVs, CVs and DVs</td>
</tr>
<tr>
<td>Operator training</td>
<td>Full attendance and understanding of operating with APC</td>
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</tbody>
</table>
Production/economic planners involvement is typically as follows:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Roles</th>
</tr>
</thead>
</table>
| Feasibility studies | Setting of economic objectives  
Providing economic variables and other data for benefits estimation |
| Controller basic design | Provide feedback where optimisation issues are involved |
| Plant pre-test | Provide window for pre-test |
| Plant step test | Provide window for step test |
| Performance test run / Project wrap-up / post commissioning review (SAT) | Provide window for step test |

Instrument engineers’ involvement is typically as follows:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Roles</th>
</tr>
</thead>
</table>
| Feasibility studies | Providing control system architecture  
Availability of connection port to control network  
Determination of use of OPC software or vendor software on DCS  
Compatibility of any third party software to the DCS  
For software to be installed on DCS, determination of availability of hardware, hardware capacity, control network capacity  
If utilizing new DCS-based hardware, identify if DCS cabinets have sufficient space  
If utilizing new external hardware, identify physical location requirements and cabling requirements and routing  
For external hardware implementation, identify security issues, connection to firewall, antivirus installation and updates (to check with iPerintis) |
| Base layer performance review and improvement work | Solve instrumentation issues |
| Plant pre-test | Standby to solve instrumentation issues |
| Plant step test | Standby to solve instrumentation issues |
| On-line installation and tuning | Assistance for system integration of APC software with DCS  
Feedback comments during commissioning  
Assistance with modification of control strategies as application  
Assistance with loading and testing of APC software  
Assistance with additional coding for shed manager  
Assistance with any other coding requirements, for instance for building of purpose built Inferentials |
3 SCOUTING STUDY/FEASIBILITY STUDY

The initial investment for an APC project can be substantial as it involves cost implication in engineering services (if external parties are involved), buying the hardware and software. Subsequent investments will be the software licenses (maintenance fee) and manpower in maintaining the APC. Therefore, it is important to identify upfront that the plant will benefit from implementing the project.

An MPC is normally used where:

1. Interactive processes exist, where changing one MV will affect many other CVs, e.g. fractionation and reaction processes.
2. Varying economics exist, i.e. changing the yields depending on prevailing market prices, e.g. crude distillation units and FCCU.
3. More constraints than variables to adjust, e.g. fractionators, reactors and separation trains.
4. There are more variables to adjust than variables to control such as in some distillation columns.

These process units normally have MPC available:
- Distillation processes and reactors
- Acid Gas Removal Unit
- Hydrocracker
- FCCU
- Coker
- Lubes extraction
- Ethylene
- Other Chemical plants

There are two aspects in this study. Each aspect identifies/signifies different issues:
- Benefits study identifies the benefits that will be obtained from the project. This involves studying the economic drivers of a site.
- Readiness-for-implementation study identifies the site readiness for the project. This involves looking at the site’s organisation, Base layer controls and data infrastructure.

3.1 BENEFITS STUDY

A site-wide benefits study is best handled by a small multi-disciplinary team. The team should include representation from site production/economics planning, operations, technologist and control/system engineer. Benefit identification requires both technical and inter-personal communication skills. Identification and benefits realisation requires:

1. Understanding the economic driving forces for the processes.
2. Understanding how the processes work and interact.
3. Understanding the process’ real limitations and constraints.
4. Obtaining buy-in for the benefits and solutions from the end users (operations and technologists).

During the benefits study, potential APC applications are identified. Some guidelines that can be used for this assessment:
- Review current plant performance against production targets.
- Review the economic drivers’ added value potentials.
- Benchmark the plant with other best performers in same production line.
- Consider any expected process changes.
- Use existing steady state models that have been correlated to actual plant data to identify any opportunities for control improvements.
- Identify the effects that the control improvements may have on other units as there may be an increase to intermediate products.
Consider downstream units’ capabilities to accept the increased product rate.

The list of potential applications and their benefits shall be reviewed appropriately to rank and for further study on their potential benefits.

### 3.1.1 Quantification of Benefits Study

Each item in the list of the potential applications has to be studied further in detail. The strategy here is to:

1. Identify application objectives.
2. Identify representative period of operation.
3. Collect and validate process data.
4. Analyse data for performance against targets.
5. Identify control application improvement.
6. Analyse control infrastructure performance and requirements.
7. Apply appropriate economics.
8. Categorise benefits on a confidence basis.
9. Review and agree benefits analysis with site.
10. Set-up post-application benefit audit basis.

For existing plants, data used should be actual production rates and production targets.

For new plants, data can be obtained from equivalent data of similar operations or steady-state simulations.

A sample of benefit calculation is attached in Appendix B.

Alternatively, quantification of benefits can be done together with a pre-test. The reasons are as follows, which one or more may apply in sites depending on their approach to the implementation of the Advanced Control:

1. To have a better feel on the dynamic of the process particularly on Petrochemical plant. This will help to get a first cut of controllers’ objectives and strategies on top of the statistical data retrieved from the Plant Data Historian.
2. To get some estimates on the magnitude and duration of each MVs and its effect. This will develop confidence for the real step test.
3. To estimate the number of potential MVs and CVs for better preparation in the next Step Testing during implementation phase.
4. All the potential MVs (PID controllers) conditions will be tested for any constraints, limitations or any other problems. This is to enable rectification work to be carried out much earlier before implementation phase is started.
5. During the pre-test and feasibility study, there may be a need for any additional online analysers to be included. There are instances in where data sensitivity is not sufficient for soft sensor development. This is due to its stringent purity range (e.g. separation measurement in ppm level). As such, an online analyser is needed.
6. For items 4 & 5 above, there could be some cost incurred to rectify prior the implementation phase. These can be prioritised in the order of importance, thus can be worked out.

This option may inevitably cost more as it will require more active participation from the vendors/external parties.

### 3.1.2 Application objectives

Firstly, the proposed application objectives shall be identified by discussing thoroughly with representatives of the site. The process limitations/constraints and production targets/objectives shall also be carefully looked at and challenged. Every claim on benefits and constraints shall be backed up by supporting data to ensure that these are real and not perceived.
3.1.3 Data collection and verification

In order to validate the potential benefits identified in the benefits study, all the necessary information and data shall be obtained. The data collected shall be sufficient and of a sensible timeframe to be statistically significant and consistent.

The data required is listed below (but not limited to):
- Production targets – product rates, quality
- Actual process data – achieved rates and quality
- Control system performance – valves, control loops
- Process operating constraints and limits including reasons and the values – throughputs, equipment and valve sizing limits, limitations due to downstream units/equipments, planning, safety or environmental restrictions
- Plant/unit availability, i.e. stream days – scheduled/unscheduled downtime allowances
- Availability of measurement – e.g. temperature, analysers; include reliability, accuracy, repeatability
- Discrete events such as crude drum switching
- Future economic and process modification scenarios

Any assumptions made shall be agreed by the site personnel. Assumptions can be made for any missing data or information.

Plant data can be collected either from a plant historian or straight from DCS. It shall be noted that not all sites historises DCS data for a long period of time especially for a period sufficiently long for a benefits study. It shall be noted that a month’s data is required for the assessment.

The information collected shall be in sufficient quantity and representative of the actual operation. The period selected cannot be a shutdown or turndown operation period. Normal variations such as weather and day/night operations should be included. Gross errors in benefit calculation can occur if these operational modes were not accounted for. Where lab data is infrequent, it is an even more critical to lengthen the data collection period for this part of the study.

Any data collected shall be checked for its validity before computing the benefits. Bad data shall be filtered out, where not normal operation was found. Use site-wide data reconciliation where available. Data compression shall be removed for this period.

3.1.4 Readiness-for-implementation Assessment

The Readiness-for-implementation assessment involves a different type of study. This assessment looks at:
- Site’s organisation – manpower availability to implement and maintain the APC applications.
- The state of the Base layer controls – are the instrumentation, controllers and control system in good health.
- DCS loading capacity – can it take additional loading due to the extra application that will be added in.
- Data infrastructure – important for data gathering and maintenance of the APC applications.

Before the implementation of APC, existing Base layer controls shall be checked to be in proper working condition. As APC applications work with this layer, these shall be in good health. The instrumentation shall be in good working condition to ensure smooth controls. The controllers shall be in the right mode of operation & properly tuned. Refer for base layer review for further information.
Finally, this document shall at least concentrate on the following:

1. Process overview
2. Current and future operating objectives
3. Economics used in benefits prediction
4. Benefits prediction analysis, including assumptions made and references to all data sources.
5. Functional specification and scope definition of application:
   - Description of control objectives.
   - List of control Input & output.
   - Implementation platform requirements, i.e. APC and OPC server.
   - List of control/measurement upgrades required.
   - Control infrastructure upgrade requirements, i.e. additional control processor.
   - Preliminary estimates of implementation costs, including the following:
     i. Application hardware and software including license fees.
     ii. Engineering (man-hours, travel and living).
     iii. Owner’s costs, support, training, documentation.
     iv. Measurement additions and upgrades.
     v. Regulatory control upgrades.
   - Preliminary schedule.
   - Plans for post application audit.

3.1.5 Base layer Assessment

A Base layer assessment shall be done during or after the feasibility. The corrective actions shall be done before starting plant step tests as the step tests require the Base layer controls to be in their proper working order. It affects the models’ reliability and tuning when the applications are commissioned.

There are several things to be checked during this review:
- Controllers performance - properly tuned and in the desired mode.
- The instruments such as measuring instruments and the control valves are properly working. These shall also be reliable and accurate. The ranges shall also be checked against future possible changes due to the control improvements. The sensors should also be checked for noise, while the valves free moving & has minimum hysteresis.
- Control strategy - meets the desired intent and the proposed control improvements by applying the APC applications.

There is some software available in the market that can facilitate in this part of the activity. The considerations include:
- Checking the regulatory controllers’ uptime.
- Evaluating controller performance. This means looking at the following:
  - Standard deviation.
  - Quarter-amplitude decay.
  - Settling time.
  - Deadtime.
  - Stiction.
  - Error analysis.
- Check for noise in measurements.
- Check for instrumentation limitations, e.g. valve, measurement range and other problems.

Refer to Appendix C for a checklist for Base layer performance that is acceptable before proceeding with an APC project.
3.2 **MASTERPLAN**

For sites with multiple APC potential, a masterplan for APC implementation is recommended. The masterplan shall, at minimum, contain the following:

- Definition of the long term objectives and phasing of the work
- Prioritising of APC applications.
- Manpower availability during implementation and for maintenance once project is completed.
- Project timeline – schedule and milestones.
- Project capital investment required – e.g. complete infrastructure layout, plant area network connections, communication gateway, servers and software license strategy.

At this stage, involvement from the same multi-disciplinary team during the feasibility study is recommended. At the end of this study, Management of the site should commit to this Masterplan by agreeing on the investment required; both on monetary requirements and organisational needs (manpower and organisation structure). This applies not only throughout the project period, but also throughout the lifecycle of the APC application.

3.3 **FUNCTIONAL DESIGN SPECIFICATION**

The functional design defines the MPC control objectives and the design purpose. Each MPC will have their own sets of MVs, CVs, DVs specified.

This document contains at least the following:

a. Description of the application objectives and functions.

b. Definition of control technology and communications methods.

c. Scope of DCS, regulatory control and measurement improvements.

d. I/O requirements.

e. Model details.
   i. Expected MVs, CVs, and DVs.
   ii. Estimated response time for each controller.

f. Operator, engineer and maintenance interfaces.

g. Requirements for turning the application on and off, and shedding or control degradation behaviors.

h. Maintenance requirements.

i. Training requirements.

4 **PROJECT PLANNING AND CONTRACTING**

Please refer to PTS 10.003.

5 **PRELIMINARY MODEL DEVELOPMENT**

Commercial software comes with model identification tools which may differ in modelling technique. Generally, the process of modelling involves similar methodology regardless of software. Most offer data input validation, bad data slicing, modelling, inferential quality estimator builder and other variety of functions.

It is highly recommended for the control engineer involved in the model development to attend software training if unfamiliar with the software provided. This is to ensure that the applications can be properly monitored and maintained once installed and commissioned.
5.1 CONTROLLER FINAL DESIGN

At basic functional design, preliminary selection has been made on MVs, CVs and DVs. At controller final design MVs, CVs and DVs may be revised according to the findings of the Base layer assessment.

There is also a need to finalise the boundaries of the MPC controllers; will it be a big single controller overseeing multiple units or smaller ones for single unit operations. A big controller enables unit-wide optimisation and is better able to handle common constraints between sub-units. The advantages of having smaller controllers are:
- Less diverse range of CV response times.
- More control over possible MV/CV pairings.
- Easier to step test as it takes less time.
- Easier to commission.
- Higher service factor.
- Trend to individual controllers, one for each tower or other unit.

5.2 CHOOSING MANIPULATED VARIABLES

PID loops may be left closed or opened, where the MPC controller writes to the PID loop setpoint or output.

The situations where a PID loop should be left closed:
- Where it is more effective in eliminating certain disturbances due to the higher frequency of application, e.g. flow control loops.
- Certain pressure, level and temperature PID loops.

There are situations where a PID loop should be opened, i.e.:
- Loops with very long dynamic (high process lag) and/or large dead time.
- Process lines with two control valves in series.
- Depending on the control strategy, some level controller may be left opened as it can provide more effective decoupling, i.e. using levels as buffer for process variations.

Some good control engineering tips:
- Ensure that the MVs have direct and immediate affect on the CVs.
- Use computed MVs to reject certain disturbances, e.g., use internal reflux control to reduce the effect of rain storms or computed heat input for a pump-around.

The following are some guidelines in choosing MVs:
- Independent of other MVs and all DVs
- A good MV should have
  - Significant effects on some CVs
  - Model predictable effects on CV’s
- Use MV for control when
  - It is a value with a fast, strong and predictable effect
  - MVs with a good range to move
- Use MV for optimisation when
  - MVs with a slow but long-lasting effect
  - MVs with a less predictable effect

Note that every MV is used for control, but not necessarily for optimisation. Some MVs are obvious as operators normally use them but there are some that is required as an MV but is hardly manipulated by the operators. The penalty of leaving any MVs out is having to re-do the plant step test all over again!
Some examples of an MV:
- Reflux flow
- Reboiler flow or duty
- Tray Temperature
- Overhead Pressure
- Feed Temperature

5.3 CHOOSING DISTURBANCE VARIABLES

A DV is an independent variable which affects the process, but it cannot be manipulated within the MPC. It may exist as an MV in another MPC. The MPC uses the information to compensate for them using the available MV within the MPC, i.e. just like feedforward. A change in DV shall be independent of MVs and other DVs. Its effect may be dependent on other MV/DV.

A good DV should have significant effects on CVs, give reliable measurement and provide dynamic advantage to the MPC. The penalty of getting it wrong means more step testing or worse, affecting performance of controller since controller won’t know their effect.

Some examples of DV are
- Feed flow from previous column.
- Feed temperature.
- Feed composition (using analyser).
- Ambient temperature.

5.4 CHOOSING CONTROLLED VARIABLES

There are 3 main types of CVs:
- Regulated, i.e. to improve unit stability.
- Restrained, i.e. operational limits.
- Optimised, i.e. to implement PVO.

A CV shall be dependent on at least one MV.

The following are some guides in choosing a good CV:
- Use calculated CV, e.g. CV transformation that linearise the overall response of the process, internal reflux ratio instead of reflux flow.
- Consider the service factor (reliability) and good correlation with lab results for analysers.
- Consider including the existing key CVs for operator comfort/acceptability.
- Set up proper bad value handling.
- Check for parallel CVs.

It is better to have too many CVs at the start than too few.

The penalty for getting it wrong will be none, so long as we collect all the measurements on the process unit. Anything missed out can always be included later.

Some examples of CVs are
- Strategic tray temperatures and/or pressure compensated tray temperatures
- Analysers or inferred calculations
- Delta pressure
- Valve Positions
- Conversion Calculation e.g. in FCCU
- Other calculated variables
5.5 \textbf{INFERRED PROPERTY CALCULATIONS}

An inferred property calculation provides real time continuous process values for control. It eliminates time delay in process values and provides real time continuous process values for information.

There are several methods applied in these calculations:
1. First Principle-based method - based on chemical engineering principles.
2. Data Regression-based method - developed by correlating data.

The most widely used is the data regression method as it is the simplest without sacrificing quality.

The data regression method requires data of relevant process variables, e.g. temperature and pressure. The process variables data is regressed against measured stream property data to generate a correlation between them. Therefore, the correlation developed is used to predict stream property and analyser/laboratory values are then used to correct the predicted values.

For the data regression method, it is necessary to have a good online analyser/laboratory update system. There should be a user interface for these values to be entered into the inferential calculation programme. Once the analyser/lab value is updated, it enables update of the bias value in the inferred property equation.

If there are significant thermodynamic property changes in the process, the preferred technique is the first principle method due to its robustness and accuracy. One example is the failure of regression based inferentials during crude switching in a crude distillation column. This occurs due to a significant change in thermodynamic properties of the feed and thereafter significant change in crude unit equilibrium conditions. In this situation, first principle inferentials shall be utilised.

Inferred Property Calculations are done by determining stream properties using measured process variables such as temperature and pressure. The stream property is inferred instead of measured. Calculations can be based on engineering principles, empirical correlations, or a combination of both. Calculated values are corrected with lab values when available. Example calculations are D96 temperature, flash point, RVP and pressure compensated temperature.

It is also important whenever updating the bias values to ensure that the lab/analyser values are giving out the correct reading. In this case, SPC methods are critical to reject statistically questionable analysis.

6 \textbf{STEP TESTS}

6.1 \textbf{PRELIMINARY STEP TESTS}

Preliminary step tests are an initial activity to verify the functional design specification and to identify & verify the suitable step size for the actual step tests. From the process knowledge gained through experience and/or discussion with the site experts, a preliminary gain matrix can be developed. During pre-step test, MVs and DVs are step-tested once or twice to obtain a preliminary model in the form of matrix.

The matrix will show expected relationships between each inputs (MV & DV) and outputs (CV). The matrix will show "+" as a positive gain, "-" as a negative gain and "0" for none in the matrix. In practice, inputs are listed vertically while outputs are listed horizontally.
The preliminary step testing sets the ground work for the actual plant step tests. The plant pre-test shall take place during normal operating condition. During the pre-test, some checks need to be done to have good results during the real test. These are:

1. Check all the sensors, control valves and regulatory control loops for proper operation.
2. Ensure that the process equipment is in proper working condition. Material and energy balances are checked on the unit.
3. Apply step input changes for each MV and compare to the preliminary gain matrix.
4. Reconcile any deviations from what was expected (e.g., preliminary gain matrix, dynamic response, etc.). This will enhance process understanding.

All the MVs and DVs shall be pre-stepped in their desired controller mode intended for APC. The following guide simplifies what is expected from the preliminary step tests:

1. Move each MV/DV 1 step up, 1 step down.
   - This can prove that the basic controllers work and valves have a sensible operating range and don’t go fully open or fully closed during normal operation.
   - It may not be possible to step all the DVs all the time.
2. Approximate time to steady state.
3. Estimate the extent of dynamic relationship between MVs, CVs and DVs.
4. Identify any potential problems to be resolved before the actual step tests.
5. Develop a good actual step test plan with the knowledge gained from pre-step test.
6. Build any other schemes required i.e. ratio controllers and switches.
7. Draw preliminary model.
Drawing up a preliminary model helps with identification later. It is highly recommended to do it during the pre-step test. It does not have to be accurate but it shall be directionally correct. An example of the preliminary model is as below.

![Preliminary Model Example](image)

### 6.2 PLANT STEP TEST PLANNING

It is important to plan the step test in order to ensure that no surprises occur during the actual test. The plan shall be comprehensive and shall include but not limited to strategies, schedule (time & manpower) and methods (step test & data collection). The control engineer prepares the step test procedure, i.e. the plan for the step test.

The steps involved are at least the following:
1. Establish a step test documentation which includes procedure, what parameters to moves, move sizes and safety precautions, etc.
2. Collection of uncompressed data during the exercise – ensure all necessary information is available in the data historian, how it is collected and assessed for their quality.
3. Discussions with operations (e.g. experienced console technician) on the plant conditions/constraints, and to agree on the step sizes and direction of moves.
4. Give the assurance that the plant/process will not be distressed. Step tests will always disturb the normal operating pattern, but controlling the level of disturbance is necessary so the plant can always be brought back to the normal operating level at all times during the step test.

As step tests may possibly cause some minor interference to normal plant operation, it is necessary to gain Management’s approval before starting the test. If the interference is significant, the test shall be suspended and the step test plan shall be revised. Even the size and duration of moves shall be agreed upfront. The plan shall be reviewed and agreed with the other team members.

In developing the step test procedure, all the MVs and DVs can be tabulated as follows:
- Tag number and physical description
- Nominal operating values
- Range of move sizes
- Estimated process gain & settling time
- Make a proposed testing move sequence.
- Discuss the MV move sizes with operations. Remember the specification and constraints.
6.3 **ACTUAL PLANT STEP TEST**

The objective of a step test is to obtain process dynamic information. This information shall be used to develop the dynamic model between all MVs, DVs, and CVs for the MPC. It is crucial to obtain a most representative model of the process is needed in order to ensure a robust MPC.

Step testing requires significant effort. It is important to carefully prepare for step testing. Planning is crucial and the following shall be done or checked prior to the step test:

- Data collection method. The data shall be uncompressed and any exception functions are removed.
- Finalise regulatory control configuration.
- Correct known flaws in basic instruments and control.
- Regulatory instruments & analysers are running well.
- Inputs to inferential calculations are working and identified upfront.

A step test perturbs the process by making moves (output or setpoint) on the selected MVs & DVs in order to collect data. Any process responses shall be observed and recorded diligently. It is necessary that discussions take place with operations (e.g. experienced console technician) to get them to understand the objective of the step test. This is to ensure they do not try to counteract the effects of the step test. The step sizes shall be agreed with operations prior to the test, ideally 5-10% of the nominal process value.

The main step test is similar to the pre-step test but requires more number of steps and takes a longer time to complete. Every MV and DV needs to undergo a series of step changes. These have to be stepped in both directions for linearity. Repeat the steps many times with different duration of multiple time constant and under different modes of operation if they may affect the model. It is necessary to monitor and record every move and events of the process during the step testing. Arrange for any process samples earlier to correlate analyser(s) or inferential property calculation. Keep some trends of responses especially if it is unusual as they may be helpful later.

The approximate minimum time for step testing is given as

\[ 6 - 7 \times (NMV + NDV) \times TTSS \]

where:

- NMV = no. of MVs
- NDV = no. of DVs
- TTSS = average time to steady-state

Example, if TTSS = 2 hrs; NMV+NDV = 23; estimated duration of step test = 7*23*2 hrs = 14 days.

Ideally, it is the control engineer who will run the step test. Console operators or other process engineers should assist but they may be required on another unit which needs their undivided attention.

The following are some tips for a successful step test:

1. Brief the operators (5-10 min) at the start of each shift and explain what was and is to be done.
2. Make sure that each MV and DV move is made according to plan, in the proper direction, and by the correct magnitude.
3. Occasionally check whether the trends match with the preliminary gain matrix that was prepared earlier.
4. Plot real-time data and note all the behaviour that was seen.
5. Identify abnormal periods and make notes: significant unmeasured disturbances, instrument failures, utility outages. The MPC model should not be trained using data collected during these periods.
If the MPC models do not agree with the process, controller reliability and performance will be poor. Any process changes (e.g., different equipment configuration, different feed, different regulatory controller tuning, etc.) will result in mismatch between the MPC model and the process thus, affecting controller performance.

6.3.1 Treatment of Unmeasured Disturbances during step tests

Training data set used for model identification which contains unmeasured disturbances will reduce the accuracy of your model and effectiveness of the overall project. Some unmeasured disturbances are inevitable, but these shall be kept at absolute minimum. Some disturbances are unavoidable, e.g. rain, day/night variations. Some examples of unmeasured disturbances to be avoided during the step tests are:

1. Back flushing a condenser.
2. Changes in by-pass streams.
3. Product grade changes.
4. Changes in the controller settings for the regulatory controllers.
5. Any change in the process operating conditions not modelled in the controller or process equipment changes.

If there are any data collected during the periods with unmeasured disturbances, slice out the data from those periods so that this data is not used to train the MPC model. Therefore, the identified model will not be corrupted.

6.3.2 Correlating moves during step test

Another pitfall during step test is correlating moves. For example in Figure 3, if we move the flow in and then compensate this by moving flow out, then we are making a correlating move.

![Figure 3 Example for correlating moves](image)

Another way of correlating moves is by always moving reflux up and then reboiler down or vice versa. This will affect model identification process. The safest way not to correlate moves is to move one variable at a time. Move one variable up and then back down again, repeat when necessary and only then move onto the next variable.

There are two step testing methods that are known; conventional method (single input single output) and Pseudo-Random Binary Numerical Sequence (PRBNS). Conventional method is done by stepping the variables one at a time, whereas PRBNS makes multiple moves at the same time.
6.3.3 Conventional method

This is the most common method where one MV is moved at a time within a defined MPC boundary.

The advantages are:
- Good for obtaining the final steady-state gains.
- Straight-forward and easy to understand.

The disadvantages are:
- Poorer at modelling early dynamics.
- Have to make quite big moves.
- Labour intensive.
- Tend to do more moves than necessary.
- Takes longer.

Step-size made shall be more than noise and each has to be waited out, depending on the process, at least for 1/4, 2/4, 3/4 and 1 TTSS. Operators can help to do the steps if there are no unit problems and especially if they are familiar with MPC. It is again important to avoid correlating moves consistently.

Some tips and guidelines to be used during conducting the step test:
1. Try as much as possible to make large moves as this gives a better measure of steady-state gains
   - Move at least 6 x noise level.
   - Shall have operations agreement for size of move.
   - Step away from safety constraints, e.g. reduce pressure first then only increase it back.
2. Only change one variable at a time to avoid complication during observation of responses, though sometimes may need to break this rule.
3. No dependant variables should be controlled (unless valve positions, etc.)
   - Break all Cascades (level to flow, temperature to flow etc.)
   - Turn off all APC.
4. Keep process within its normal range of operation.
5. Avoid measurements reaching low or high limits.
6. Avoid MVs reaching output limits, setpoint limits, etc.
7. Monitor process carefully and tell operators if there are any problems.
8. Keep a logbook to record all that happened during the test. Also, record:
   - Any changes from the test plan.
   - Other changes and the reason for the change.
   - Any controller modes that is incorrect.
   - Controllers that fail.
   - Controllers that drive their valves to fully open or closed.
   - Any comments about the way the test is proceeding, e.g. write down if real inverse response is observed or any other unexpected response so you can look back on these later.
9. Make from 5 to 15 step tests for each MV.
   - The MV changes should be as random as possible to prevent correlated data.
   - MV moves should be as large as possible but not so large that it upsets the process (e.g., 3-10%).
   - For each MV, make a change after 1t_p, 2t_p, 3t_p, 4t_p, and 5t_p, where t_p is TTSS/4.
10. Above all, remember the product specifications and the process constraints.
7  MODEL IDENTIFICATION, EVALUATION AND DEVELOPMENT

At this stage, process models have to be developed in order to get the relationship between relevant MVs, DVs and CVs for the Multivariable Controllers. The chosen software package should come with MPC model identification software. Each of the input/output Step Response Model (SRM) models shall be developed from the accepted plant step test data.

Examine every SRM sub-models especially gain, order of the model, time constant, settling time and residual plot. Residual plot will help identify the degree of process nonlinearity. It will also help evaluate CV transformations that behave more linearly.

Use process knowledge to analyse the SRM sub-models before making final model selection.
  o Clean data
  o Data format for ID
  o Model ID - refer to step test logsheet

Next step is to create perceived models of the process from the data analysis above. Again, the chosen software package also comes with an offline modelling package to build the model. Normally, the offline application for modelling is setup and installed on a stand-alone PC. It is advised to attend the training and/or to refer to offline application manual for modelling.

Once the offline models are developed, it is recommended to review the models together with other parties, e.g. Operations, Process Engineers, Control Engineers and Planners to ensure that the models are sensible. The models have to concur with what is known of the plant. The plant experience is extremely important at this stage as no model is perfect and may require adjustments to make it acceptable. Among the most important parameters are:
  1. Gain sign – there should be a process explanation for the direction
  2. Settling time
  3. Order of the process response

Select the best fit model for an MV-CV pair. Once the models are found satisfactory, these can be loaded to the Final Model. For every sub-model, these can be done separately.

Some snapshots taken from Honeywell’s RMPCT at different steps of model development:
Figure 4  FIR Fit

Figure 5  Model Selection
7.1 CONTROLLER OFFLINE SIMULATION

Once the developed models have been reviewed and controller built, these MPC has to be run in a simulation mode to check on their performance and robustness. Again, the simulator is also supplied by vendor as it is normally included inside offline application for MPC identification and development. At this stage, preliminary controller settings are also obtained; also called tuning the controller.

The process model is first run against itself to check for any errors. Next, ‘what-if’ scenarios are used. If necessary, modify the model. It is important to know what is being done, so either referring to the offline application manual for modelling, or attend the vendor training.

There are 3 important things that need to be right at this stage:
1. Economics
2. Constraints
3. Dynamics

In testing the economics of the controller, the controller need to be simulated (off-line) with different combinations of constraints to ensure that the controller pushes the plant in the correct direction. It is also necessary to run test cases to see which constraints are operative.

Prior to starting simulation, MVs and CVs ranges should be set around existing plant’s parameters. With the controller turned on in optimising mode, the MPC will control all CVs within limits as long as there are enough degrees of freedom. One will have no degrees of freedom when the number of manipulated variables equals to the number of constraints (both CV and MV).

Degree of freedom =
= \{ \# of Inputs\} – \{ \# of constraint inputs (t) + \# of constraint outputs (t) \} at time t
= \# MV – (\# ||CV|| + \# ||MV||)
Tune the relevant MPC parameter (CV rank, Equal Concern Error, MV weightage, LP cost, Maximum move, etc) so that if the APC cannot meet all CV ranges, it will give up on the CV which has been defined as the lower priority. The CVs depends on the CV rank and Equal Concern Error. The MVs depends on the MV weightage and Maximum move. Please refer to the vendor’s manual for specific definition and settings.

This offline simulation allows users to simulate controller behaviour, e.g.

1. CV limit violations – reactions to single and multiple violations
2. MV responses – during CV violations and normal actions, in the event of reaching high and low limits
3. Reaction to process disturbances

At this point in time, operator training can also be conducted in order to familiarise the operators with the MPC. This is especially useful if this is the first time it is implemented in the plant as operators do not have any idea what an MPC is like. It is always a good idea to conduct operator training for new applications, i.e. either new installation or upgrades. A good operator training will increase the success of the MPC application. This is done as part of the Factory Acceptance Test (FAT).

The offline application will create/generate files (e.g. configuration file) that contain data and configurations for the MPC online to work with DCS environment.

### 7.2 MPC ONLINE INSTALLATION

For online installation, it is necessary to refer to the specific Vendor’s Manual to ensure that correct steps are taken. At this stage, the offline models and controller files will be transferred to APC server. Depending on the MPC software provided, controllers are installed into a separate APC server with a historian embedded into it communicating to the DCS system via an OPC server. Alternatively, the APC server with its process data historian and OPC server can reside in a single server. This depends on the size of the MPC application and the DCS data traffic to the MPC application.

In addition, a number of graphics/schematics have to either be created or modified as part of user interface for the operators or APC engineers. This includes standard graphic interface for the MPC and trend/schematics/graphics screens. It may also be necessary to add some switches/DCS blocks in order to transition to MPC control or fallback to regulatory control.

### 7.3 MPC COMMISSIONING

Before running the controller, the following needs to be checked and understood to ensure that the commissioning will not cause major upsets to the process and instrumentation:

1. Ensure that transition of controls from regulatory to MPC and vice-versa is smooth and easy for the operators to handle and understand.
2. Ensure that the MPC shall be able to handle any input/output failures (e.g. MV have a bad value) and the MPC responds accordingly as expected. If any substitution is done due to the failure, this shall be highlighted on the monitoring screen so that it can be rectified as soon as practicable.
3. Initialisation of the controller and its effect on the regulatory controls shall be understood as it can adversely affect the process if wrongly done.

Once all configuration files have been generated and MPC controllers checked for readiness, the MPC is now ready for commissioning. This means that it is time to run the APC on DCS environment in a real live plant. Since this is the first time it is running, APC engineers should:

- conservatively set parameters (tuning, rate of change or move, limits etc.) in MPC,
- carefully plan how/what to commission first,
- discuss with operation (e.g. experienced console technician) on the current plant conditions/constraints, and
- not upset plant/process

The commissioning shall start methodically and slowly, i.e. enable the MV one at a time. The controller shall first be set to standby mode to check for any errors. Having a checklist helps in proceeding with caution. The checklist shall include, but not limited, to the following:

1. The operators have been trained
2. Control software, database, and other real-time components have been installed.
3. Controller database shall be checked for the following:
   - Control CVs, DVs, and MVs shall match raw DCS inputs exactly
   - Controller models, tuning parameters, etc. match off-line versions exactly
4. Ensure that the relevant inferential application is running
5. When the controller is switched on to the prediction mode,
   - Each MV is configured correctly as in the DCS
   - Shed mode is correct for each MV
   - Any MVs fall out of cascade (controller cannot change mode)
   - Controller is actually turned on the prediction mode
   - The size of the calculated DV moves are sensible
   - The CV predictions make sense
6. For a first-time MV check,
   - Use conservative controller settings.
   - Reduce difference between upper and lower limits on MV (or rate limits).
   - Controller is running.
   - Put MVs into cascade one at a time.
   - Ensure that the calculated MV change is applied to DCS setpoint.
7. In closing the loop,
   - Turn on the controller master switch.
   - With MVs clamped, put one or two MVs into cascade.
   - Relax the MV limits somewhat and check for good controller behaviour.
   - Add more MVs gradually, ensuring good control performance.
8. For final checks,
   - Ensure that the standard deviations of the CVs decrease and that the MVs are not moving around too much.
   - Ensure that the optimisation mode is driving the process in the correct direction.

The MPC should be monitored continuously during the early stages that it performs as per design intent. Once the operators are assured that the MPC is running smoothly, the following should be done in order for the MPC to push the process to the limits:

1. Adjust the MV and CV limits accordingly.
2. Turn CV, MV and/or DV off when necessary.

Initially during commissioning, MVs and CVs are set tight. MV limits should be loosened as much as possible once confident with the controller’s performance. If they are set too tight, then the controller simply “sits” on the MV limits. Limits should also be set so as not to cause controller to move the process to an undesirable condition.

For CV limits, these are the actual control parameters. There are 3 types of limits:

1. Safety – set at safe limits (normally fixed), e.g. high pressure
2. Operational - set so as not to cause plant to hit constraints e.g. hydraulic limits such as output of valves, set at 5% and 95%
3. Quality - set appropriately e.g. C5 low limit = 0.2% and high limit = 2%

CV limits can be set as high and/or low, or even crimped together to make them into a setpoint.

Turning any MV, DV or CV off (making it inactive) will change the controller mode. It also depends on the criticality of the variable, i.e. whether it was set as critical or non-critical. If a critical MV is turned off, then the controller will automatically turn off. If it is non-
critical, when it is manipulated, MPC regards it as a DV. If too many MVs are turned off then the controller is forced to turn off as well because it has insufficient handles.

If a critical CV is turned off then the controller will automatically turn off. If it is non-critical, then the controller will ignore it and no longer try to control it.

If the MPC often hits the MV/CV limits, it may be necessary to challenge these limits unless for safety limits or hard constraints. The APC engineer has to ascertain whether the limits are real limits together with the operations and process engineers. If the limits are real, allow the MPC to continue. Otherwise, the APC engineer should decide whether the limit can be moved. If it cannot be moved, then the APC engineer should think of ways to improve the situation, e.g. open a bypass, or get a valve re-sized at next shutdown, or debottleneck the unit and many other ways.

The MPC shall be observed to fine tune the controller actions, i.e. too slow or too fast. The lab data should also be updated into the relevant inferential application.

### 7.4 MPC MAINTENANCE AND IMPROVEMENT

The controller has to be monitored continuously throughout its lifecycle, as to ensure it is performing according to its design intent. Based on industry research, lack of support and online monitoring will adversely affect the controller performance. Its benefits can quickly erode and can be as fast as 2 years!

![Figure 7 Lack of monitoring erodes the benefits of APC (reference)](image)

The MPC performance shall be monitored continuously. Even any ‘major’ changes e.g. process changes (new feed, plant load), equipment changes (wear & tear of equipment e.g. control valves) or process/equipment design changes shall be monitored and observed. Over time, some sites have unknowingly experience the deterioration in the APC performance. When necessary, the MPC Models shall be updated to suit the changes.

Some possible causes of deteriorating performance are:

- Human factor, e.g. incompetent workforce, improper & insufficient trainings/exposures, no sense of ownership, doing irrelevant tasks etc.
- Limited people to look after the controllers (MPC, ARC etc).
- No ‘special’ tool makes the work very tedious, thus inefficient.

Among the items to be monitored are:

1. Main controller, MVs, CVs, DVs uptimes, limits violations, control indexes, APC model errors, optimisation & tuning factors etc.
2. Health of base layer controllers, e.g. normal modes, tuning parameters, etc.
A separate PTS for this is currently being developed.

**Figure 8 Example of an APC Performance Metrics**

### PERFORMANCE AUDIT

The key success indicator of any APC application is its economic performance. There should be performance metrics indicating how economically successful it has been. It should be simple and provide direct indication to the performance of the unit. Some examples of performance metrics that are commonly used include:

a. Measurement of the cost of production per unit of feed or product.
b. Measurement of energy use per unit of feed or product.
c. Total throughput.
d. Product yields.
e. Product quality and variability relative to specifications.

The economic performance of an advanced control application should be evaluated at several points during its life. An initial performance should be determined for pre-project operation. A second assessment is determined during a post-project audit. This second value then normally becomes the baseline for comparing the values that are obtained at other intervals for continuous improvement. The baseline performance metrics may require re-evaluation as modifications are made to plant equipment or operating objectives.
9 MPC DOCUMENTATION

All types of supporting documentation shall always be maintained and kept up-to-date. The documents are as follows:

1. Feasibility study report – reference for post-audit
2. Masterplan Study
3. Detailed Design document
4. As-built documentation – controller settings
5. Operator/Engineer training manuals
6. Vendor manuals
7. Software backups
8. APC database

This includes backups of the software and databases besides the hard copy documentation. All of this shall be kept in a secure location to ensure that all information is not lost and traceable for reference. Where possible, try to make all the records (from all steps) that are available in hardcopies into softcopies by scanning. There is also a need to establish ‘as-built documentation’ for the controller which includes detail inputs and calculations of all the parameters (CVs, MVs, DVs, DCS tags, Inferentials etc.). These shall be treated as a controlled item. It may also be important to keep all the discussion notes throughout the implementation phase as it may provide insight to new engineers/operators as to why a certain parameter is used or why a variable is chosen and not the other.

Another issue that is always overlooked is change controls. Sometimes, modifications to the controller are necessary to ensure continued excellent performance. Change control refers to procedures to ensure that modifications are made in an approved manner and are properly executed, tested and documented. This can be included in the sites’ existing Management of Change (MOC) procedures and guidelines.

10 REFERENCES

2. Introduction to MP, Petronas Skill Group Development Programme course
APPENDIX A: QUESTIONS FOR PROCESS UNDERSTANDING

In summary, to check the understanding, the following questions below can be answered

- What is the purpose of the plant/unit?
- Where does the feed come from?
- Where does the product go?
- How much flexibility is there for feed supply and product demand?
- How do the seasons affect the operation, feed supply and product demand?
- What are the 3 or 4 most important constraints that operators worry about?
- Where the source of energy is used (gas, steam, etc) and how expensive is it?
- What are the product specifications?
- Are there environmental or tax issues that affect plant operations?
- Does feed composition changes and if so how often and how fast are these changes?
- What is the current constraint on throughput? Are these equipment / safety limitations?
- Have there been historical incidences of higher than normal throughput and what conditions allow for these?
- What is the typical yield of the unit?
- What parameters impact yield of the unit? Are any of these constrained?
- What is the benefit of incrementing yield?
- What are the cost values of the feed and products or unit margins?
- Where does the product go?
- What are the specifications of the product?
- What impact is there in violation of product specifications? And how much is tolerable, if at all? What is penalty of such violation?
- Is the product blended in line or at tank or is it straight-run? Is there room for minor offsets in composition of product?
- How much flexibility is there in operating the unit?
- What is the unit run days per annum? (used in computation of annual benefits)
- Are there seasonal fluctuations in demand or in feed delivery?
- Are all the base layer controllers in automatic?
- On a typical stable operation shift, which are the handles that are most frequently operated by the operator? Are these in automatic?
- What is the stability of the key handles? During normal operation and minor / major upsets?
- Are there any issues with measurements on the process?
- Has the operator seen APC controls in action before?
APPENDIX B: BENEFITS ANALYSIS CALCULATION

Statistical analysis is an important method in analysing potential control improvements benefits. Normally, the study involves reducing the standard deviation of important process handles, e.g. product specification and moving operation closer to limits. This is a well-accepted practice in estimating the potential benefits. Generally, implementation of advanced control applications will reduce the statistical standard deviation of the target variable by 50%.

A graphical representation of benefit analysis is as below:
A sample calculation is as follows. The example in this case is maximising throughput. In this case, the production can be maximised by reducing feed fluctuation. This will result in yield increase of the product. The following is the statistical data analysis for the plant.

<table>
<thead>
<tr>
<th>Descriptions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Data</td>
<td>180</td>
</tr>
<tr>
<td>Max charge rate, m3/hr</td>
<td>345.4</td>
</tr>
<tr>
<td>Min charge rate, m3/hr</td>
<td>233.2</td>
</tr>
<tr>
<td>Current Average, m3/hr</td>
<td>279.6</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>15.32</td>
</tr>
<tr>
<td>95% Confidence Upper Limit</td>
<td>288.03</td>
</tr>
<tr>
<td>Percentage outside of max. spec. %</td>
<td>5.00</td>
</tr>
<tr>
<td>Z Factor to 95% Max. Limit</td>
<td>1.65</td>
</tr>
<tr>
<td>Achievable Standard deviation reducing rate</td>
<td>0.50</td>
</tr>
<tr>
<td>Achievable Standard deviation</td>
<td>7.66</td>
</tr>
<tr>
<td>New Average, m3/hr</td>
<td>292.24</td>
</tr>
<tr>
<td>Delta Average, m3/hr</td>
<td>12.64</td>
</tr>
</tbody>
</table>

The current average charge rate, standard deviation and 95% confidence upper limit are found by calculating from the collected data. These are calculated using statistical methods. The 95% confidence upper limit is calculated using the formula below:

\[
95\%\text{ confidence UL} = \text{Current average} + (\text{Z-factor} \times \text{standard deviation}/3)
\]

The Z-factor to 95% maximum limit is taken from the Standard Normal (Z) table. The achievable standard deviation is 7.66, i.e. 50% of current standard deviation. Therefore, the new average is calculated using this formula:

\[
\text{New average} = \text{Current average} + (1.65 \times \text{Achievable standard deviation})
\]
## APPENDIX C: ACCEPTABLE BASE LAYER CRITERIAS

The following criteria are considered acceptable in order to proceed with an APC project implementation:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Accepted Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Controller Uptime</td>
<td>75% controller in Automatic</td>
</tr>
<tr>
<td>2 Noise</td>
<td>&lt; 5% of range</td>
</tr>
<tr>
<td>3 Measuring instruments range</td>
<td>Ideally readings should lie between 15 – 80% for 80% of the time</td>
</tr>
<tr>
<td>4 Valve operating range</td>
<td>Valve at 25 – 75% for 80% of the time</td>
</tr>
<tr>
<td>5 Settling time</td>
<td>For flow/pressure (liquid), ideally measurement should settle within 5 seconds of valve movement. For others, highly dependent on process characteristics.</td>
</tr>
<tr>
<td>6 Valve responsiveness</td>
<td>For flow/pressure (liquid), ideally should have response within 5 seconds. For others, highly dependent on process characteristics. Generally, response can be seen after 1 or 2 minutes for a well-designed system.</td>
</tr>
</tbody>
</table>