

Engineering Procedure

SAEP-349

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Advanced Process Control (APC) Systems

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1 Scope

This Saudi Aramco Engineering Procedure (SAEP) with its appendices prescribes the minimum mandatory requirements and guidelines governing the planning, engineering, design, installation, testing and monitoring of Advanced Process Control Systems (APC) projects in Saudi Aramco plants. SAEP-349 is applicable to all Saudi Aramco projects either as stand alone or which include advanced process control systems.

This entire standard may be attached to and made a part of purchase orders.

In the event that some or all of the steps are executed by contractors or vendors, the project team shall ensure that the project is executed within the framework of this standard.

Selection of specific hardware or software platforms is not within the scope of these standards and practices.

This document addresses the following list of steps for justifying, implementing, and maintaining advanced control applications in Saudi Aramco refineries, gas plants and other applicable facilities:

- a) Feasibility Studies - Cost and benefit estimation
- b) Implementation and execution
- c) Inferential properties development
- d) Documentation
- e) Performance Monitoring
- f) Post-audits

2 Conflicts and Deviations

- 2.1 Any conflicts between this standard and other applicable Saudi Aramco Engineering Procedures (SAEP), Saudi Aramco Engineering Standards (SAESs), Saudi Aramco Materials System Specifications (SAMSSs), Saudi Aramco Standard Drawings (SASDs), or industry standards, codes, and forms shall be resolved in writing through the General Supervisor, Process Control Division, Engineering Services of Saudi Aramco, Dhahran.
- 2.2 Direct all requests to deviate from this standard in writing to the Company or Buyer Representative, who shall follow internal company procedure [SAEP-302](#) and forward such requests to the General Supervisor, Process Control Division, Engineering Services of Saudi Aramco, Dhahran.

3 Applicable Documents

The engineering execution of APC projects may be considered with the latest edition of the references listed below, unless otherwise noted.

The following reference contains additional information and industry guidelines (Sections 3, 4, 6 & 7) for APC applications that may be referenced.

[*API RP-557*](#)

Guide to Advanced Control Systems

4 Definitions

4.1 Abbreviations

APC	Advanced Process Control System
APCU	Advanced Process Control Unit
ARC	Advanced Regulatory Control
CV	Controlled Variable
DV	Disturbance Variable
DCS	Distributed Control System
ES	Engineering Services
ESA	Engineering Services Agreement
FPD	Facilities Planning Department
KPI	Key Performance Indicators
MIS	Management Information System
MV	Manipulated Variable
MVC	Multivariable control
OO	Operating Organization
PAS	Process Automation System
P&CSD	Process & Control Systems Department
P&ID	Process & Instrumentation Drawing
PID	Proportional, Integral, Derivative feedback controller
PT	Project Team
SAEP	Saudi Aramco Engineering Procedures

4.2 Definitions

Advanced Process Control System: Refers to any process control system application that has functions beyond those commonly associated with regulatory process control systems. Advanced Process Control Systems Application may be characterized by any of the following:

- A control system that controls or manipulates multiple variables in order to maintain one or more operating objectives.
- A control system that performs calculations beyond those that could normally be performed using standard algorithms available in DCS systems or multi-loop controllers.

- A control system that may utilize a significant number of DCS standard algorithms connected together in a complex manner.

APC is generally executed in a higher level computing resource such as a process control computer or implemented in a programming environment at lower control levels, irrespective of the complexity of the computations.

Multivariable (including blend property control), constraint and optimizing controls will be labeled advanced controls. Controls that fall into this category will be those that are supervisory in nature, i.e., they normally, but not always, output to the set points of other control loops rather than to the final control elements directly.

For the purposes of this document, a significant APC application project is defined as:

- Implemented on a reasonably sized process unit, and
- Automates the setpoint changes to most of the unit's manipulated variables, and
- Is performed either by a contractor and/or using in-house resources.

Constraints: limits in the process or equipment that should not be exceeded. Constraints may take the form of physical limits such as a design temperature or pressure or other pre-defined process limits such as a maximum feed rate, composition or other value. Constraints may be either maximum values or minimum values.

Controlled Variables (CV): process values that are maintained by the control system by making appropriate adjustments to Manipulated Variables. These are controller inputs to be kept at a set point. Examples are flow, pH, pressure, temperature, level or concentration.

Distributed Control System (DCS): A process control system is composed of distinct modules. These modules may be physically and functionally distributed over the plant area. The distributed control system contains all the modules and associated software required to accomplish the regulatory control and monitoring of a process plant, excluding field instruments, remote terminal units, auxiliary control systems and management information systems.

Disturbance Variables (DV): process input values associated with an Advanced Control System Application that are measured but are not controlled by the application. An Advanced Control System Application often takes control actions to maintain the control objectives when Disturbance Variables change. Examples are ambient temperature, feed from another unit, etc. Disturbance variables are also called Feedforward variables (FF).

Economic Variable: an indication of process economics. This variable can be directly measured using instrumentation sensors and transmitters, or computed

from other variables directly measured or values obtained from laboratory testing or other techniques.

Engineering Service Agreement (ESA): are internal written commitments between P&CSD and their customers to resolve most important issues. It is a service guarantee that P&CSD will provide and help implement a solution in the field. ESAs state the agreed upon objectives, schedules and success criteria for individual projects. Customers are simultaneously committing their support and resources.

Inferentials or Inferential Properties: are physical or chemical properties of a process stream or a batch which are calculated (inferred, thus inferential) from other readily measured physical properties such as temperature, pressure and flow rates.

Manipulated Variables: process values that are adjusted by the Advanced Control System Application to meet operating targets and desired values of Controlled Variables.

Multivariable Control (MV): a form of an Advanced Control System Application in which several control variables are maintained at desired values through a complex relationship. Several Manipulated Variables may be adjusted simultaneously in order to maintain an economic or other operating objective. Multivariable Controllers typically execute at a frequency of one minute.

Process Variable (PV): an indication of process performance, which are directly measured using instrumentation sensors and transmitters, values that are computed from these variables or values obtained from laboratory testing or other techniques.

Project Team (PT): The team assigned the responsibility of implementing and managing the project. The team may be led by a contractor (vendor), P&CSD, operating organization, or any combination of the three.

Regulatory Control: a control application in which generally one controlled variable is maintained at a desired value by manipulation of one manipulated variable. Regulatory control may also include control applications that utilize common calculations or predictions. Examples are steam drum level controls, combustion controls or mass flow calculations.

Service Factor (SF): is a measure of the fraction of time that an APC application is operating on-line over a specified period of time. It is expressed in percent.

Utilization Factor: is a measure of the effectiveness of an Advanced Control System Application. It is more than a measure of whether the application is on or off. This usually is a complex calculation that is based upon the numbers and types of sub-functions within an application, the percentage of time that the

functions are operating and the relative economic weighting of each sub-function.

5 Responsibilities

5.1 APC Project Team composition.

The APC Project Team (PT) is assigned the responsibility of implementing and managing the project. The team may be led by a contractor (vendor), P&CSD, operating organization, or any combination of the three. A project may be performed using one of the following three methods:

- a) Contractor. The contractor leads, provides all necessary manpower and has full responsibility for project completion and success under the management of the appropriate Saudi Aramco representative.
- b) In-House. Saudi Aramco employees (P&CSD/OO) lead the project and are fully responsible for all manpower, hardware and software requirements.
- c) Combination of contractor and in-house. This type of project is led by Saudi Aramco employees (P&CSD/OO) who will contract portions of the work as needed.

5.2 Process & Control Systems Department (P&CSD)

Responsibilities include:

- a) P&CSD shall be consulted before commencing any significant APC project to effectively utilize corporate resources and ensure support for long-term sustainability of the APC application. If appropriate, an Engineering Service Agreement (ESA) will be developed between P&CSD and the Operating Organization to ensure a clear vision of project objectives, responsibilities and deliverables.
- b) Ensure that the procedures in this SAEP are used to perform APC project planning, justification, implementation, testing, documentation, maintenance, and monitoring.

5.3 Operating Organization

Responsibilities include:

- a) Consulting P&CSD before commencing any significant APC project.
- b) Ensuring that sufficient engineering, operations and maintenance support are available and committed to implement and maintain the APC application.
- c) Following the procedures in this SAEP.

- d) Correcting instrumentation deficiencies that hinder APC implementation or operation.
- e) Approving final acceptance of the APC application.
- f) Review and approve any feasibility and post-audit studies/reports associated with APC.

6 Instructions

6.1 APC Feasibility Studies – Cost and Benefit Estimation

6.1.1 Methodologies of APC Benefit Estimation

Every significant APC project shall have an APC Feasibility Study performed to estimate the potential benefits achievable with an APC implementation. This requirement is not necessary if the proposed APC application is:

- a) On a process unit where an identical application and associated post audit have already been completed and where similar economics are applicable.
- b) For an APC remediation or revamp project.

This section addresses the guidelines for estimating the benefits that APC would bring to a particular process unit. APC benefits are estimated by a feasibility study (See Appendix A) and then proven by a post-audit (See section 6.5 and Appendix C).

There are four (4) major methodologies for estimating APC benefits. These are:

- a) Industry experience
- b) Best Operator
- c) Statistical estimations
- d) Simulation techniques

6.1.2 Recommended Methodologies of APC Benefit Estimation

Saudi Aramco recommends using the statistical estimation method for final justification of APC projects. Methods one (1) and two (2) may be used for preliminary selection, budgetary and project prioritization. See Appendix A for detailed methodologies and procedures of APC benefit estimation.

Generally, the funding used for APC projects is expense and not capital sourced. This is primarily due to software licensing and engineering work that make up the primary component of such projects. Any large capital funding greater than \$2MM for APC projects should follow the

Facilities Planning Department (FPD) guidelines (See their website: <http://engsvcs.aramco.com.sa/fpd/>).

6.2 Implementation and Execution

6.2.1 Implementation Steps

An APC project will generally follow a series of discrete steps or phases for an APC implementation. These steps usually include the following:

- a) Feasibility Study – Cost and Benefits Estimation (See section 6.1)
- b) Procurement/Contractual Development
- c) Controller Scope/Preliminary Design
- d) Kick-off Meeting
- e) Plant Pretest
- f) Formal Plant Test
- g) Modeling and Simulation
- h) Commissioning
- i) Training
- j) Documentation

A project may reduce the number of steps by combining certain functions. Also, functions in some steps such as training and documentation may be completed at various times throughout a project.

Each project phase is described in more detail in the following sections. The description includes recommendations and "best practices" that should be followed. Tables 6.1 through 6.10 except for Table 6.3 list specific deliverables for each project step and which organizations are involved in producing that deliverable. Table 6.3 list which organizations will take responsibility, assist or approve specific project tasks.

6.2.2 Procurement/Contractual Development

This task will likely need to be performed in conjunction with part of the next step, Controller Scope/Preliminary Design, in order to have a good handle on project scope to meet procurement requirements.

Advanced Process Control implementations generally use expense funding due to required software licenses and the large amounts of engineering time and effort required.

Software licensing requires a contract as per Saudi Aramco contracting procedures. P&CSD has extensive experience in APC contracting issues

and is the sponsor of several GCS contracts for APC vendors. P&CSD shall be consulted before commencing any APC projects to effectively utilize corporate resources and ensure support for long-term sustainability of the APC application. If appropriate, an Engineering Service Agreement (ESA) will be developed between P&CSD and the operating organization (OO) to ensure a clear vision of project objectives, responsibilities and deliverables as shown in Table 6.1 below.

Table 6.1 - Contractual Agreements and Personnel Requirements

Deliverables	Personnel Requirements (Involvement indicated by 'X')					
	Contractor (if used)	P&CSD	OO/APC Eng	OO/Opns	OO.Maint	OO/Lab
Labor and software licensing Contracts	X	X	X			
Engineering Service Agreement (ESA)	X	X	X			

6.2.3 Controller Scope/Preliminary Design

During this phase, P&ID's are reviewed and a tag list is developed along with the initial controller design. The envelope or scope of the controller(s) is established and a list is developed of the preliminary manipulated variables (MV), disturbance variables (DV), and controlled variables (CV). The control objectives and required inferentials are reviewed as shown below: See Table 6.2.

Table 6.2 - Scope/Preliminary Design Deliverables and Personnel Requirements

Deliverables	Personnel Requirements (Involvement indicated by 'X')					
	Contractor (if used)	P&CSD	OO/APC Eng	OO/Opns	OO/Maint	OO/Lab
o Tag list	X	X	X			
o Preliminary controller design(s)	X	X	X	X		
o Project Steps and Schedule	X	X	X			
o An Inferential Development and Implementation Schedule	X	X	X			

6.2.4 Kick-off Meeting

A kick-off meeting shall be held at the plant site with all project personnel involved in the project. This includes Vendor consultants, P&CSD engineers, and from the operating organization (OO) including

representatives from operations, maintenance and engineering groups. A responsibility table shall be developed to clearly present a summary of personnel roles pertaining to specific project tasks. Personnel involved may represent OO, central engineering or contractor. See Table 6.3 below for an example of an APC project led by a contractor or P&CSD. A kick-off meeting is held to:

- a) Review detailed description of process operation, control objectives, and historical operating and control issues.
- b) Confirm the project scope.
- c) Review and confirm the project steps and schedule.
- d) Review the initial controller design (initial list of matrix variables).
- e) Review existing inferentials and establish an inferentials development and implementation plan.
- f) Review step testing procedures.
- g) Develop pre-test plan.
- h) A formal Kick-Off Meeting minutes report delivered to OO/P&CSD within one week after the kick-off meeting.
- i) Form a team and define responsibilities for the members.

Table 6.3 lists deliverables and personnel requirements for this step.

Table 6.3 - Example of APC Project Responsibility Table

Task Description	OO	P&CSD/ Contractor
Pre-Testing	A	R
APC Calculation Design, Configuration and Commission	A	R
ARC Design and Commission	A	R
Step Test Plan	X	R
Step Testing	A	R
Model Identification	A	R
APC Controller Generation & Testing	A	R
Detailed Design Document	A	R
Detailed Design Review Meeting	X	R
Engineer Training		R
Operator Training	A	R
APC Controller Commissioning	A	R
As Built Documentation	X	R

Legend: **R**: Take Responsibility or Action, **A**: Assist, **X**: Approve

The deliverables are listed below in Table 6.4.

Table 6.4 - Kick-off Meeting Deliverables and Personnel Requirements

Deliverables	Personnel Requirements (Involvement indicated by 'X')					
	Contractor (if used)	P&CSD	OO/APC Eng	OO/Opns	OO/Maint	OO/Lab
o Minutes of Meeting	X	X	X	X	X	X
o Responsibility Table	X	X	X	X	X	X
o Pre-Test Step Plan	X	X	X	X	X	X

6.2.5 Plant Pretest

The first step in the implementation of an advanced process control project after the kick-off meeting is the pretest. A pretest procedure document should be developed and endorsed by the OO before the start of the pretest. The following should take place during the pretest:

- 6.2.5.1 Verify the suitability of the existing preliminary design of the controller strategies including the configuration of the regulatory controllers under the proposed MVC controller. If changes in configuration of the base regulatory system are required, the plant should operate in this new mode for at least one (1) day with an engineer present to determine that there are no underlying problems with the new configuration.
- 6.2.5.2 Establish estimated gains, responses, noise, and linearity where possible.
- 6.2.5.3 Identify control tuning issues and initiate immediate steps to remedy them.
- 6.2.5.4 The filtering of all critical signals should be reviewed for noise. Noisy signals should have the filter increased to remove the noise as best as possible or use a heavily filtered copy of the variable if it is not appropriate to filter – e.g., the variable is also an input to a safety system function.
- 6.2.5.5 Identify potential process problems that may effect controller implementation.
- 6.2.5.6 Verify functionality of critical instrumentation required for the controller. Identify any shortcomings in the regulatory controls and field instrumentation and determine remediation steps. This includes valve hysteresis, slip/stiction and positioners.

- 6.2.5.7 Determine the necessary manipulated variable step sizes, acceptable operating ranges and laboratory support requirements.
- 6.2.5.8 Collect historical process and laboratory data as necessary to support inferentials development and evaluation and preliminary model identification. Ensure that all required tags are being collected.
- 6.2.5.9 A control diagnostics product, if available, should be used to help diagnose and identify regulatory control problems with the selected manipulated variables on the process units.
- 6.2.5.10 Any calculated variables such as pressure compensated temperatures required for the controller are developed at this stage of the project, implemented in the DCS if possible, and added to the data collection before the formal plant test.
- 6.2.5.11 A logbook shall be created to note important observations that occur during the pretest such as problematic control valves and instrumentation, and poorly tuned controllers.

Many vendors now offer intelligent step testing products that can automate the actual stepping portion of the testing. These include Smart Step from Aspen Tech, Profit Stepper from Honeywell and Tai-Ji Identification from Tai-Ji Controls. The use of these offerings is recommended whenever possible because they have been proven to reduce testing time and provide guidance for better quality of model data collection. The following table 6.5 below identifies "best practices" for plant step testing.

Table 6.5 - Step Testing "Best Practices" and Guidelines

Item No.	Practice	Description
1	Independent Movement	Do not move a second manipulated variable (MV) consistently at the same time as another MV or at the same relative time to the other MV.
2	Minimum Movement Size	Step sizes should be large enough to have an effect on the process that is at least 6 times the noise level in the measured variable – this is the control variable (CV). The moves should be as large as operations will allow.
3	Hold Times	Hold times (time between moves) should be varied

		between approximately $\frac{1}{4}$ of the settling time of the process and about $1\frac{1}{4}$ of the settling time. The hold times should be varied randomly and uniformly over this range. The average hold time should be approximately equal to $\frac{1}{2}$ of the process settling time.
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4	Model during Test	Start model identification during testing. Models should be checked each day to identify areas where additional testing may be required.
5	Move Steady State	Push towards known constraints if possible. This will mimic what the optimizer will do.
6	Monitoring Saturation	Monitoring all control valves, bypasses and analyzers to ensure that none are at saturation. Saturation will invalidate step data.
7	Test Non-Linearities	Step test variables that may show non-linearities. These will need to be identified to be linearized later.
8	Good Communications	Real-time communications with all project team members and operations is very important. Maintain a log of all abnormalities such as sudden weather changes, saturations, bypasses, etc.

Following this pretest activity:

- 6.2.5.12 All deficiencies identified during the pretest are rectified. Items are categorized as: High importance, Medium importance and Low importance. It is imperative that the formal plant test does not proceed unless all of the High importance items are completed.
- 6.2.5.13 The new regulatory controls proposed in the preliminary design shall be configured, implemented and tuned as required for the formal plant test.
- 6.2.5.14 Implement any inferential property calculations that are completed.
- 6.2.5.15 Develop the Formal Plant Test Plan to provide the greatest amount of information across a wide range of response frequencies in the shortest amount of time. The plan will specify the details of data collection including recommended manner of collection, required software, etc.

See Table 6.6 below for deliverables and personnel requirements for the Pretest step.

Table 6.6 - Pretest Deliverables and Personnel Requirements

Deliverables	Personnel Requirements (Involvement indicated by 'X')					
	Contractor (if used)	P&CSD	OO/APC Eng	OO/Opns	OO/Maint	OO/Lab
o Regulatory controller tuning summary	X	X	X	X	X	
o Instrument/equipment repair check list	X	X	X	X	X	
o Formal Plant test plan	X	X	X	X	X	X
o Preliminary plant test report.	X	X	X	X	X	X
o Update the Preliminary Design.	X	X	X	X	X	X

6.2.6 Formal Plant Test

Plant testing is started once all necessary repairs to the instrumentation and regulatory control layers are completed. The Plant Step Test is conducted to obtain data on process dynamics, gains and loop interaction. See Table 6.5 for testing guidelines and Table 6.7 for deliverables. Similar to the pretest phase, a formal plant test procedure document (See item 6 of Table B.1 in Appendix B) shall be developed and concurred by plant operations before the start of the plant test.

6.2.6.1 During a plant test, each independent variable is stepped up and down a sufficient number of times to obtain an acceptable model. This number may be between 3 to 12 times or more depending on various factors. Data is collected generally on a one minute frequency for the entire test. The collection frequency will depend on a variable's time-to-steady-state. The test is conducted on a 24 hour basis, with continuous engineering coverage, to collect as much continuous data as possible.

6.2.6.2 Automatic step testing software such as SmartStep (AspenTech Inc.) or ProfitStepper (Honeywell Inc.) should be considered, if available. Automatic testing typically requires a good knowledge of the plant gains to ensure safe operation and should only be used if appropriate. It is strongly recommended that safety critical processes (such as reactors, etc.) are manually stepped.

6.2.6.3 Preliminary model identification is performed throughout the test to ensure that the quality and quantity of collected data are sufficient to facilitate good controller development.

- 6.2.6.4 The plant test is carried out in close cooperation with the console operators. In case of manual plant test, the console operators are consulted on all step moves and make the required set point changes. If this is an automatic test, then the steps moves maximum sizes are determined by discussions with the console operators. The set points changes are made automatically if an automated step testing tool is used. The plant test is a good time to start discussing the APC application with the console operators and performing some training.
- 6.2.6.5 If the required inferentials have not been completed, it will be necessary to collect lab samples during the plant test above and beyond the normal samples collected. The additional sample load could be manpower intensive therefore extra laboratory personnel may be required for the task.

The step test deliverables are listed in Table 6.7.

Table 6.7 - Plant Test Deliverables and Personnel Requirements

Deliverables	Personnel Requirements (Involvement indicated by 'X')					
	Contractor (if used)	P&CSD	OO/APC Eng	OO/Opns	OO/Maint	OO/Lab
o Plant Test Response Data	X	X	X	X	X	X
o Plant Test Log	X	X	X	X	X	X

6.2.7 Modeling and Simulation

- 6.2.7.1 After completion of the plant test, the plant response data is analyzed using the off-line data analysis tools. The relationships between all of the independent variables (manipulated and disturbance) and the dependent variables (controlled) are identified, and placed into a model matrix for use by the controller.
- 6.2.7.2 The resulting model matrix defines the dynamic relationships between the manipulated variables in the controller and the variables it controls.
- 6.2.7.3 Once the controller model is built, economics are developed. The economic information and the off-line simulation software shall be used to simulate the entire controller.
- 6.2.7.4 Tuning factors are adjusted to get the desired response action of the controller. Initial controller parameters for

commissioning and field tuning shall be established from the simulations.

- 6.2.7.5 The detailed design is finalized and a final design review meeting shall be conducted.
- 6.2.7.6 A commissioning plan shall be developed and then reviewed by the proponent.
- 6.2.7.7 The off-line controller configuration file from the off-line controller simulation shall be used in the online system.
- 6.2.7.8 Additional database points required for the controller are built, any operator screen changes are made, and the controller is started up to run on live plant data in open loop mode.
- 6.2.7.9 Verification shall be performed of all controller predictions along with the constraints the controller is operating against. This includes uncompensated predictions to check for model accuracy.
- 6.2.7.10 Verification shall be performed of all process values, manual entries and calculated values.
- 6.2.7.11 Check all graphics and operator interface procedures. Ensure that all related engineering and operator displays are available and functional including laboratory update screens.

Table 6.8 below lists the deliverables and personnel requirements for this step.

Table 6.8 - Modeling and Simulation Deliverables and Personnel Requirements

Deliverables	Personnel Requirements (Involvement indicated by 'X')					
	Contractor (if used)	P&CSD	OO/APC Eng	OO/Opns	OO/Maint	OO/Lab
o Final Process Model Matrix	X	X	X			
o Detailed Controller Design Document	X	X	X	X		
o Initial Controller Parameters	X	X	X	X	X	X
o Controller Simulation File	X	X	X			
o Commissioning Plan	X	X	X			

6.2.8 Commissioning

6.2.8.1 Once the interface has been checked, the controller is ready to be commissioned according to the developed plan.

6.2.8.2 Informal training of the operators shall be conducted prior to and during the commissioning process. For most of the first week, the commissioning is covered for 24 hours/day. After the first week of commissioning, the coverage is scaled back and there is a continued focus on informal training.

6.2.8.3 Saudi Aramco shall verify successful startup and shutdown of controllers including shedding to backup regulatory control schemes on the PAS. Shedding verification for bumpless transfer shall include loss of critical input to APC, communication failures, or any other situation that may inhibit the APC from performing safely.

6.2.8.4 Saudi Aramco shall verify the performance guarantees as specified in the contract.

Table 6.9 below lists deliverables and personnel requirements for this step.

Table 6.9 - Commissioning Deliverables and Personnel Requirements

Deliverables	Personnel Requirements (Involvement indicated by 'X')					
	Contractor (if used)	P&CSD	OO/APC Eng	OO/Opns	OO/Maint	OO/Lab
o As-Built Engineering detailed design document	X	X	X	X		
o Minutes of final Commissioning review meeting.	X	X	X	X	X	X

6.2.9 Training and Technology Transfer

6.2.9.1 The operations personnel shall be provided with hands-on training at the time the control system is commissioned. The operator displays, functionality and the control objectives shall be explained at this time. This training should provide the operations personnel with an understanding of how to interface with the control system.

6.2.9.2 Formal training of the operators shall be conducted during appropriate project phases. The formal training shall cover some background on the APC control technology, the objectives of the controller, the specifics of using the controller interface, and any other important points associated with using the controller.

6.2.9.3 Saudi Aramco engineers assigned to the project shall also become experienced with the control technology and implementation steps through active involvement throughout the project phases. The objective is to ensure proper technology transfer so that they may carry out the long term maintenance of the control system.

6.2.9.4 An operator training manual shall be developed.

Training deliverables are listed in Table 6.10.

Table 6.10 - Training Deliverables and Personnel Requirements

Deliverables	Personnel Requirements (Involvement indicated by 'X')					
	Contractor (if used)	P&CSD	OO/APC Eng	OO/Opns	OO/Maint	OO/Lab
o Operator training class	X	X	X	X		
o Operator Training Manual	X	X	X	X		

6.3 Inferential Properties Development

6.3.1 Inferential Development

- 6.3.1.1 The use of an inferential calculation shall be considered for all controlled or monitored properties associated with an APC application whether or not an on-line analyzer exists or not and assuming that the properties are capable of being calculated by state properties such as flow, temperature and pressure, and lab results are available.
- 6.3.1.2 An on-line, reliable analyzer is always preferred over an inferential calculation only. The best engineering practice is to have an inferential backed up by an analyzer (See section 6.3.2). Regardless of analyzer quality, most analyzers have slower cycle times than that of the APC application. A properly designed inferential will allow the APC to continue operating for a reasonable period of time in case of analyzer failure.
- 6.3.1.3 The development of inferentials shall be based on a representative period of operational data. This includes consideration of product specifications, seasonal variations in the plant conditions and products, efficiency changes in equipment such as fouling and catalyst deactivation, etc. Special care should be taken in selecting the process data used in developing the inferential models. Process data should be properly aligned with the lab analysis results and/or analyzer reading. Furthermore, the process data needs to be checked for the effect of data compression employed by data historians; highly compressed process data may not be useful for inferential models developed due to the loss of key features in process variables behavior in some cases.
- 6.3.1.4 The choice of inferential input variables shall be based upon known engineering relationships as much as possible.

6.3.2 Inferential Feedback

- 6.3.2.1 Inferred properties shall be developed to augment on-line analyzers to provide instantaneous feed back to the APC controllers. The inferred properties shall allow either lab or analyzer feedback, typically updating the bias.
 - 6.3.2.2 The operator or APC engineer shall have the capability to suspend the feedback. If feedback is automatically suspended based on feedback data validation, it shall not be re-established automatically. Operator or APC engineer intervention is required to re-establish feedback if it has been suspended.
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6.3.2.3 The APC engineer (or the operator) shall also have the capability to select and change the lab (or analyzer) bias fraction that is for updating the inferential. Suspending feedback is also equivalent to setting the bias fraction to zero. The on-line inferential shall have the capability to reject outliers, frozen signal, and feedback values that exceed a pre-specified rate of change.

- Lab Feedback - The operator shall have the facility to evaluate the inferential prediction after lab feedback, and have the option to reject the feedback.
- Analyzer Feedback - The inferential shall have the facility to accept a signal from the analyzer indicating that a new result is ready to be read. The inferential package must accommodate the dynamic differences (deadtime and lag) between the analyzer and the predicted quality result when using feedback from an analyzer.

These facilities for feedback shall be available to the operator and/or APC engineer via a display in the DCS system.

6.3.3 Inferential Validation

6.3.3.1 Property inferentials shall have validation on the input signals, feedback signal, and the final inferential output. As a minimum validation shall include signal validity checking, high and low limit checking, freeze checking, and spike detection.

6.3.3.2 The inferential shall have the capability to declare some inputs as "critical" such that the inferential can be declared a bad value result or cease to operate if a critical input fails the validation check. Failure of feedback validation shall not cause the inferential to stop predicting. The operator shall be notified (via message or alarm) if the feedback signal does not return to a good signal within a specified period of time.

6.3.4 Documentation

The documentation for the inferential shall include the following information:

- a) Validation limits.
- b) Model form and explanation for choice of form.
- c) All inferential tuning parameters.

- d) Description of original dataset, and record of data manipulation prior to inferential development.
- e) The correlation of each input variable to the predicted property.

6.3.5 Interface

6.3.5.1 Operator

The operator shall be notified (via message or alarm) if the inferential ceases to update due to critical input variables failing validation or ceases to update on feedback due to feedback signal failing validation.

The inferential monitoring screen shall show the active status of feedback. A mechanism must be provided on the inferential interface to deactivate and activate the feedback.

For lab feedback, the operator shall have a mechanism to enter the lab data and timestamp. Preferably, the interface will allow an operator to use a simple software switch to enter a timestamp at the time of sampling.

6.3.5.2 Engineer Interface

The engineer's interface shall allow access to all aspects of the inferential model. This includes tuning parameters, feedback filtering, any feedback statistical calculations used within the inferential, validation parameters, and the unbiased prediction.

6.3.6 Security Access

The operator shall have access to enter lab feedback information, and to reject the result of a particular feedback calculation. The operator shall also have the ability to suspend analyzer or lab feedback to the inferential indefinitely.

The operator may be allowed view-only access to other aspects of the inferential if desired. All other access to the inferential shall require engineering access to modify the inferred properties.

6.4 APC Project Documentation

The complete engineering and operating documentation for an APC application shall consist of the components listed and detailed in the appropriate tables in Appendix B. As a minimum all documentation shall be electronically compiled on a CD and provided to the Aramco operating organization site representative, and a copy shall be provided or retained by ES/P&CSD/APCU.

6.5 Performance Monitoring

6.5.1 General Requirements

- 6.5.1.1 Each installed APC application with multivariable control shall be included in a new or existing APC Performance Monitoring package that has been approved by P&CSD. P&CSD maintains a recommended list of such vendors.
- 6.5.1.2 The performance monitoring application shall be able to monitor the performance continuously without disrupting the MVC and PID closed loop operations. The performance analysis results shall be available at the supporting APC engineers' desktops through the company's intranet using web-enabled technology. It should use intelligent messaging via DCS displays, workstation displays, or email for performance exceptions or alerts.

6.5.2 MVC Performance Monitoring

The performance monitoring package shall adhere to the following minimum requirements:

- 6.5.2.1 Provides MVC controller health status through key performance indicators (KPI's) that are simple in nature and portray concise information. Examples of these indices are:
 - a) MVC controller ON/OFF: To be used to indicate if MVC is turned on and being used to control a process unit.
 - b) Service Factor: Is a historical trend of the ON/OFF status for a controller.
 - c) Utilization factor: To measure how effectively the MVC is being utilized during the time it is in-service.
 - d) Constraint analysis: Charts showing the number, distribution and identification of actively constrained Control Variables (CV's) and Manipulated Variables (MV's) over a time period.
 - e) CV's/MV's statistics: This KPI will include standard deviations for CV's/MV's, CV's/MV's target errors and CV's/MV's limit errors.
 - f) MVC model quality: Verification of model quality by measuring unbiased predictions and prediction errors.
 - g) CVs/MVs limit change frequency: Track number of times that operator limits are changed over a one week period. Excessive changes indicate trouble.

- 6.5.2.2 Provides immediate key statistics with the ability for the engineer to solicit additional information on-demand through trends and "drill-down" processes if the higher level indices indicate a problem.
- 6.5.2.3 Indicates more than just whether or not the application is on-line. They shall show how effective the MVC controller is accomplishing its objectives.
- 6.5.2.4 Monitors the performance of critical MVC-supporting applications and systems such as inferential calculations and analyzer performance.
- 6.5.2.5 Monitor potential symptoms created by any degraded controller function that negatively impacts performance.
- 6.5.3 Regulatory Control Performance Monitoring
 - 6.5.3.1 Regulatory control loops malfunctions can severely impact the APC application performance. It is recommended to monitor the PID loops performance.
 - 6.5.3.2 The PID monitoring software application should be able to calculate KPIs such as, but not limited to:
 - a) Performance index: The performance of the PID loop can be compared to a benchmark loop performance. Several criteria can be used such as minimal variance, closed loop time constant, rise time, etc.
 - b) Oscillation index: This index will detect loops that show oscillating behavior and measure oscillation frequency.
 - c) Valve Stiction/Hysteresis index: When possible, valve Stiction/Hysteresis level should be estimated.
 - d) Loop delay estimation: The monitoring application should include a dead time calculation using PV and OP data only.
 - e) Standards deviation: The variance of the process variable (PV), the Setpoint (SP) and the Controller Output (OP) should be monitored.
 - 6.5.3.3 The PID monitoring package should include capabilities to sort PID loops by level of performance and pinpoint the ones that need attention. Whenever possible, the package should include capabilities of detecting the origin of performance degradation (Tuning problem, Valve/transmitter problems,

interaction, external disturbances) and gives indication of possible remedies.

6.6 Post-Audits

- 6.6.1 All significant APC applications should have a post-audit performed.
- 6.6.2 The post-audit is an essential tool for accountability of spent funds. This serves to inform management of actual benefits obtained in order to receive management support for maintenance and further control opportunities.
- 6.6.3 The purpose of this section is to provide a set of guidelines to characterize how well an advanced process control (APC) project satisfied its objectives. In addition, this document will present different approaches to benefits estimation as well as several guidelines to ensure consistent basis of comparison between the before and after APC process information. See Appendix C for detailed instructions.

Revision Summary

30 November 2004

New Saudi Aramco Engineering Procedure.

Appendix A - APC Feasibility and Benefit Estimation Methodologies

A.1 Estimating Methodologies

There are four (4) major methodologies for estimating APC benefits. These are:

- a) Industry experience
- b) Best Operator
- c) Statistical estimations
- d) Simulation techniques

Saudi Aramco recommends the statistical estimation method for final justification of APC projects. The first two methods may be used for preliminary selection, budgetary and project prioritization. The simulation technique may be the most accurate and comprehensive but depends heavily on accurate process steady-state and dynamic models. The development of these models can be very resource demanding and prohibitive in cost. This method should be considered only if such models already exist. The first two methods are discussed below in more detail.

Industry experience benefits are usually published or presented by implementers of APC technology or vendors of APC offerings. These benefits are based on an aggregated average across similar processes based on twenty years of industry experience and well publicized. Minimal effort is required to use experience numbers. One needs only to identify the process and the throughput and look up the generic industry benefit with some interpolation for the throughput. This "rule of thumb" method has an accuracy of only $\pm 30\%$ at best since a proponent's process may be different in design, operation and economics. This method is not recommended for formal justification use within Saudi Aramco and is generally used by proponent's who have not implemented APC previously and suitable for budgeting purposes only.

The 'Best Operator' method is the next easiest to perform. It only requires historical data for some key process controlled variables (CV). The average value of a variable is then compared to the best achievable by an operator. The difference between the average and the best operator represents the potential improvement with APC installed. The assumption is that the APC will consistently perform like the best operator. Accuracy with this method is around $\pm 20\%$. This method is not recommended for final justification use with Saudi Aramco since it assumes that APC can do no better than the best operator and optimum operating conditions may be outside the historic operating region of the plant.

The recommended statistical estimation method is presented in detail in the following sections. See Table A.1 for a summary of the estimation techniques.

Table A.1 - APC Benefit Estimation Methodologies

Method	Effort Required	Accuracy	Comment
Industry Experience	Easy	$\pm 30\%$	Use for budgeting and preliminary selection only
Best Operator	Easy	$\pm 20\%$	Use for preliminary selection only
Statistical	Moderate	$\pm 15\%$	Recommended
Simulation	Difficult	$\pm 10\%$	Use only if models exists

A.2 Statistical Methodology of APC Benefit Estimation (Recommended Method)

The statistical method is the most widely used methodology for estimating benefits prior to the implementation of APC. It takes the form of a formal "Feasibility Study." This method requires more effort than the best operator approach, because of the need for more extensive historical data and statistical calculations. The mean and standard deviation of the data are calculated. A reduction in the standard deviation is assumed based on experience with similar applications. This reduction is the greater stability that APC can provide. Statistical formulas based on confidence regions are then used to estimate the possible changes to the data mean value enacted by APC, which results in the benefits.

Although statistical analysis of plant data is usually the best way to accurately estimate APC benefits, there may be cases when this approach is not valid. Some refinery processes have characteristics that tend to invalidate the statistical approach. For example, an objective function that is based on maximum product rates may invalidate estimated benefits that rely on reduced variability in the process. In these cases, another method, such as the simulation method should be explored.

A.2.1 General Requirements for Identifying APC Benefits

- Understand the economics and business objectives of the processes.
- Understand how the processes work and interact.
- Understand the process' constraints.

Process plant data should be collected and analyzed. Opportunities for improving the process economics should be discussed with the site personnel to:

- a) Compare actual plant performance with production/operating targets,
- b) Compare plant performance with other benchmarks.

- c) Consider any anticipated process plant modifications or expansions.
- d) Identify improvements that have been realized by existing Advanced Control System applications.

A.2.2 Plant Data Collection

Proper collection of meaningful historical data is essential to the credibility of a feasibility report.

The following types of data should be collected in sufficient quantity to be statistically significant and consistent.

- a) Product specifications.
- b) Operating targets - such as product qualities, rates, yields.
- c) Actual values achieved - feed and product rates, yields; laboratory and on-line analyzer results.
- d) Process operating constraints and limits, reasons and values should be collected under as wide a variety of operations as possible. This could include throughputs; pressure/flow/temperature limits, valve position and equipment capacity limits, limitations imposed by other processes or planning restrictions, environmental restrictions or safety restrictions.
- e) Availability of process (stream days) and reasons for outages or restricted operation.
- f) Measurement availability - analyzers, flows etc., including accuracy, repeatability and reliability.
- g) Discrete events such as coke drum sequencing, dryer switches, etc.
- h) Control system performance indicators such as poorly performing control loops, control valves, etc.
- i) Future plans and timing for process modifications and their potential impact.
- j) Production operating target changes, which may be planned.
- k) Future operational flexibility requirements.
- l) Economic driver data and long term plan.

Assumptions will have to be made where necessary data and information are not available. Assumptions relative to missing data and the impact upon the confidence of economic predictions should be discussed with and accepted by site personnel.

A.2.3 Statistical Analysis of Benefits

An important method in analyzing potential control improvement benefits is statistical analysis. Control improvement generally results in reducing the standard deviation of controlled variables (targets, setpoints) and moving operation closer to constraints. Often a 50% reduction is assumed, but the current value of the standard deviation should be considered and evaluated before assuming further reduction. Often a 50% reduction can be somewhat conservative as shown by actual audits of control applications. The improvement in standard deviation will translate to tighter control to specifications and targets, and can be represented in financial terms.

The statistical calculations can easily be performed in a spreadsheet such as EXCEL.

It should also be noted that the improvement in stability of the controlled variables is often achieved by more frequent adjustments of the manipulated variables. However, the net effect is a reduction in variability of the controlled variables.

Another valuable analysis is to compare operations variability among operating crews. Often significant benefits can be quantified by performing sensitivity analysis and comparing "best" and "worst" operations versus average process unit operation. This figure can then be used to estimate a realistic reduction in variability.

Skill is required in selecting which prediction method to employ. Limitations in information or current capability may indicate one method when in fact another is more appropriate. It is also necessary to consider the time weighted average of control targets when those targets are changing.

The prediction of reduced variability may then affect the overall process yield, feed rate or energy usage. Economic factors for these effects should be readily available from the site. The same data can be obtained from a rigorous steady state process model and appropriate pricing information. Such a model can also be used to assess the impact of the predicted change(s) on other process parameters to confirm that the change is realistic and viable with respect to known process operating limits/constraints.

It is likely that several operational and economical cases must be examined to present a realistic view of potential APC benefits achievable. It is essential to be able to predict if any increased yields of products due to APC do not negatively impact downstream units, storage capacity or ability to sell the extra production.

The following steps shall be generally followed to calculate benefits:

- a) Determine current feeds and product production from averaged historical data that includes both process and lab. An accurate material and energy balance is required at this step.
- b) Compare the current production with maximum possible (based on previous capacity runs if available) and system design capabilities.
- c) Calculate the average variability of CV's that impact economics based on historical data. Compare these averages with maximum and/or minimum specifications to determine the opportunity increase or delta in profits. These may be calculated based on true boiling point curves (TBP) to determine volume increases or decreases. The amount of shift in CV's typically can be 50%, but a smaller or larger number may be calculated depending upon process gains and degrees of freedom available
- d) Ensure that material and energy balances are maintained after calculating potential increases/decreases in product yields.
- e) Using valid projected corporate market prices for feed and products to calculate estimated benefits over at least the future 5 years.
- f) A review of the current and future market to accommodate the predicted increases in product shall be conducted with the relevant Saudi Aramco marketing organization.
- g) Where throughput increases are predicted with APC, an engineering review of the existing downstream systems and storage capacity shall be made. Any required changes to downstream systems or storage capacity for APC shall be documented and associated costs estimated. Downstream changes may not be required for successful APC implementation but may represent additional opportunity benefits to be considered.

Experience has demonstrated that post-implementation audits are only as good as the quality of the pre-implementation (base case) information. The base case must be fully developed before implementation to ensure validity of a post-audit.

The information and data produced for a benefits prediction study provides a very sound basis (Base Case) for carrying out a subsequent post-application audit. The application implementation will always be in the future. Hence, it is important that the impact of any intervening changes; both non-control (process modifications, catalyst/target changes, etc.) and control are evaluated to check the validity of the base case.

Appendix B - APC Project Documentation

B.1 Documentation Requirements

Table B.1 lists the minimum documentation requirements for an APC project.

Table B.1 - Minimum Documentation Requirements for APC Projects

Item No.	Document Title	Description
1	Pre-Audit/Feasibility Benefits Study.	This study details the potential benefits that APC will provide to the process unit(s) under consideration for APC implementation. See section 5 for further details and content.
2	Minutes of Meetings	Complete minutes of key meetings shall be issued and distributed to the project team to ensure proper communication and follow-up.
3	Pre-Test Step Plan	This document outlines a very basic and preliminary controller design. It shall provide details of which manipulated variables are to be stepped, how big the moves will be and a time schedule for making the moves. It shall detail which controlled variables will be monitored along with any special or additional lab requirements. In addition, data collection requirements shall be addressed.

4	Status Reports	The project implementation team shall decide on the frequency of status reports. If a Contractor is involved, he should provide a weekly status report to Saudi ARAMCO during the times whenever the Contractor is performing work on-site. The Contractor shall provide a monthly status report to Saudi ARAMCO during the times whenever the Contractor is performing work off-site in the CONTRACTOR's offices. The report should be in Microsoft WORD format and can be emailed to Saudi Aramco. The report shall contain the following minimum items: • Project issues • Accomplishments • Existing outstanding items • New outstanding items • Present schedule and any revisions • Any other pertinent comments concerning the project.
5	Preliminary Design Document	The preliminary design documentation shall contain as a minimum process description, operating targets and constraints, control objectives and strategies, tuning, point architecture, supporting calculations including inferentials, instrumentation issues, and simplified P&IDs.
6	Formal Plant Step Test Plan	Details the procedure and schedule for the rigorous plant tests and follows the required content as described in item 3 of this table – "Pre-Test Step Plan'. It may also contain expected CV changes based on MV moves.

7	Final Detailed Design Document	Once the Plant Test, model identification and controller development are completed, the Detailed Design Documentation shall be prepared and delivered for review by Saudi Aramco prior to the controllers commissioning phase. In addition to an update of what the Preliminary Design contains, this document will include the matrixes of the final controllers, models, configurations and calculations.
8	Controller Commissioning Plan	This document describes the plans for commissioning activities for each MVC. It should contain controller design features and constraints that operations should be aware of during commissioning. It should have a commissioning schedule for each controller and MV. It should detail steps for PAS setup, operations review, shedding mode testing, and any impact to operations.
9	Operator Manual	This document is intended to introduce the plant operations staff to the applications which are installed, and to provide the essential information required to operate these applications. This document is intended to be a quick reference, not an in-depth reference manual. The reader is referred to the application specific manuals for more detailed or background information.
10	As-Built Design Document	Once commissioning of the controller has been completed as part of the field implementation phase, the Detailed Design Document will be updated and re-issued to an "as-built" status. See Table B.2 for content of the Design Document.

11	Updated P&IDs	Plant P&IDs shall be updated to reflect the APC loops, inferential calculations, and any medications or additions to the regulatory controls.
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B.2 As-built Engineering Design Document Content

Table B.2 lists the minimum required content for the as-built engineering design documentation. The sections are suggested for the document, but some can be renamed or combined if appropriate. The engineering manual shall be provided as an indexed PDF document or Microsoft Word document.

Table B.2 - Content of As-Built Engineering Design Document

Section No.	Title	Description
1	Introduction	This section shall describe the scope of the control application(s) and an overview of the project schedule to develop the controller(s).
2	Process Descriptions	This section shall provide an overview description of the process that is being controlled by the advanced controller(s). A simplified process diagram shall be included.
3	Overall Control Objectives, Challenges and Constraints	This section is to describe the "big picture" control purposes and issues. This section may be optional and included in section 4 below if the application involves only a single controller.

4	Control Objectives	This section shall provide an overview of how the controller application(s) are arranged when multiple applications are configured, and when a controller has subsections/subcontrollers. The key objectives underlying the design and tuning shall be described in written format here. The rationale for each controller's variable limits, as commissioned, shall be provided. This shall be in the form of a short 1-2 sentences description for each variable. The rationale for essential/critical variables shall be documented in this section.
5	Instrumentation Issues	Any identified instrumentation problems and issues should be fully described here along with resolutions and recommendations.
6	Control and Manipulated Variables description	The section shall list all of the variables used in the controller, including the tag name, tag description, DCS source parameter, APC variable type (MV, CV, DV, EV, etc.). Essential/critical variables shall be identified in this section.
7	Optimization and Control Economics	This section covers the optimization strategies and economics of the APC controllers. This shall include various operating modes and their impact on controller objectives.

8	Controller Tuning	The dynamic control and optimization (dynamic and/or steady-state) tuning parameters for all variables shall be listed. A short comment indicating the rationale for the choice of tuning parameters shall be provided.
9	Special Controller Procedures	If there are operating procedures, instrument maintenance procedures or considerations, or variable limit considerations specific to the control application(s), these shall be described in this section. Procedures shall also be included for controller startup, shutdown, and shedding.
10	Custom Controller Calculations	This section shall list all special online calculations done during pre-processing or post-processing of the control application(s). This includes variable transformations, custom calculations, etc. A print out of the calculations shall be included.

11	Process Automation System Configuration and Calculations	Includes hardware and system architecture of DCS with APC system. Should include configuration details/procedure of APC system within the DCS and address any site specific system issues. All new DCS tags, calculations, code, filtering, etc., created or generated to support the MVC control application(s) shall be described in this section. Any custom code written in the DCS shall be listed. All DCS configuration changes made to existing DCS tags shall also be listed. All tuning parameters of regulatory loops that are modified shall be listed. Any project related changes to the data historization should be noted and explained.
12	Inferential Property Calculations	All property inferential calculations developed as part of the control application(s) project shall be documented. The formulae shall be listed.
13	Performance Monitoring	Describes variables, interfaces and procedures for a performance monitoring component if applicable.
14	Controller Management	This section shall describe typical procedures for managing the control application(s) online. This includes starting and stopping the online MVC software, updating and changing control application tuning, or other modifications to the application(s). Special accounts, passwords, and server names required to access the control applications on the control servers shall be documented.

15	Controller Model	Controller model and gain matrices should be included. A short comment indicating the rationale for the choice of models/gains shall be provided.
16	Configuration File	Controller configuration file should be included with any customizations. All text and binary files required for the off-line and online portions of the APC or MVC application shall be provided in the as-built revision. The specific files are not enumerated since each MVC vendor implements a different structure. However, all files required to duplicate the off-line development environment data set (not included in the application software itself) and to completely rebuild the online application (not included in the application software itself) shall be provided.

Appendix C - Post-Audits

C.1 General

The purpose of this section is to provide a set of guidelines to characterize how well an advanced process control (APC) project satisfied its objectives. In addition, this document will present different approaches to benefits estimation as well as several guidelines to ensure consistent basis of comparison between the before and after APC process information.

To reap the most benefits from an APC application, it is necessary to monitor and analyze the APC application performance. In evaluating an APC project, it is necessary to evaluate the application's control, process, and economic performance measures. Benefits from APC projects are typically realized in the form of:

- Increased conversion and yield of higher value products
- Decreased utilities and energy cost
- Improved product quality control
- Qualitative benefits that improve overall operations and productivity which are difficult to quantify.

The proposed performance measures shall help identify such benefits and possibly highlight areas of opportunity for further improvements.

C.2 Post Audit Study Basis and Timing

One of the challenges in developing post audit reports is maintaining consistent basis of comparison between the before and after APC implementation process conditions and information. This consistency lends credibility that benefits reported are actual (realistic) benefits attained. The following are some guidelines that could help in establishing the study base case and timing considerations:

- a) Controller should be stable (service factor greater than 80%) and running for at least three (3) months before conducting a post audit study.
- b) Benefits calculations shall consider controller operating for 300 to 350 days per year, with a projected service factor (controller up-time) of 85%. If actual service factor is known then it shall be used.
- c) Compare the current operating condition of the plant with the conditions documented in the base case. Conditions like feed rate, feed composition, ambient temperature, season, down stream unit capacities, product specifications, etc., have to be as close as possible to the base-case data to ensure a meaningful comparison.

- d) If the above requirement is not possible, then as a minimum, base case data should represent normal plant operation, and data that is one (1) year apart is conducive to matching seasonal conditions.
 - e) Ensure that current operating conditions are normal plant or process unit operating conditions (e.g., feed rate, feed composition, quality targets, etc.)
 - f) Base case and post-APC implementation data quality must be ensured. Process upsets, excursions, and abnormal operating modes shall be excluded from the data sets to maintain a consistent basis for comparison.
 - g) Post audit report shall highlight if the base case and post-APC data are corrected for energy/material balance and/or normalized.
 - h) If for some reason, base case pre-APC data is limited or not representative of current normal operating conditions, regression based models or off-line simulation could be used to generate the base case data.
 - i) Only when all other means to obtain base case data are not possible, the controller can be turned-off for a sufficient period of time to collect the pre-APC base case information. This is not a good method for establishing a comparison as operators can learn how the multivariable controller works and try to match, and they often rise to the challenge.
 - j) Confirm quality and feed rate targets with the Production and Planning organizations at the facility. If the feed rate and feed composition are significantly different from the base case conditions, the performance run will not be representative of typical operating conditions and a meaningful comparison with the base case data will not be possible.
 - k) Confirm that important plant equipment and field instrumentation (pumps, valves, transmitters, analyzers, etc.) are working properly. Any serious instrumentation or analyzer problems have to be corrected before the performance test run can commence.
 - l) Confirm that all the important valves have sufficiently small hysteresis and stiction. Any cycles in PID controllers must be small enough not to adversely affect the controller. Any significant cycles in the process when the controller is switched off, must be corrected.
 - m) Confirm that the quality of inferential models predictions is acceptable as compared to analyzer readings and/or lab analysis results.
 - n) Investigate any process or equipment modifications made since the completion of commissioning. Major changes may change the dynamics of the process, and the controller models may not adequately represent process behavior anymore. (Additional step tests may have to be performed to improve the controller performance after a major process modification. If this is the case, include it in the recommendations.)
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- o) Product and energy prices information need to be included in the post audit report. Use of current product and energy prices is encouraged, however using pricing information from the pre-APC project benefit analysis phase (if any) may give an insight on actual vs. estimated benefits of the APC project. Whenever possible, the report shall calculate the benefits using both current and benefit analysis phase pricing information.
- p) Compare PID controller tuning present at the time of the step test with current tuning, and confirm that any changes made since commissioning does not adversely affect the controller's performance. Inappropriate tuning changes have to be corrected.
- q) Ensure that the MV and CV limits of the controller are set up in such a way as to maximize the economic benefits while maintaining safe plant operation.
- r) Observe the controller performance during the post audit evaluation period to ensure that its performance is still comparable with the results achieved at the end of commissioning. Any major issues related to the controller performance have to be identified and resolved before the post audit performance run is started.
- s) Ensure that the data collection system is functioning properly, and that all the important tags are collected at the same frequency as the base case data. Any data compression or filtering that was not active when the base-case data was collected, has to be removed for the test period. A data back-up procedure has to be in place as well.
- t) Review the data on a daily basis. Any abnormal incidents unrelated to the controller (e.g., loss of feed pumps, reflux pumps, fan trips, loss of electricity supply, or abnormal operating conditions) have to be removed from the data set. The performance run has to be extended until an adequate period of normal operating data has been collected.
- u) If controller performance unexpectedly degrades (e.g., due to a major change in operating condition or equipment changes), the post audit test run has to be stopped. If required, the controller has to be modified before the test run is restarted.
- v) Present a short training session to operations, engineering, and planning personnel explaining the post audit methodology, and the performance run conditions.
- w) Finally, it is recommended that a review process be conducted with Operations, Planning, and Engineering staff to validate and agree upon the results before the post audit report is issued.

C.3 Post Audit Methodology

APC benefits estimation methodologies typically include the use of statistical data analysis (mean, standard deviation, and variance) of process variables, or products yield and quality information represented in financial terms. Sometimes statistical methods alone cannot quantify the benefits attained from an APC application, thus a combination of these methods may be required. Other methods may include performance analysis from a material/energy balance perspective, or from a pure controller variables behavior point of view (e.g., constraints handling and cost variables information.) How these methods are applied at each site may be unique, therefore, the post audit report needs to describe the methodology followed.

Although the main objective of APC post audit studies is to highlight the tangible benefits reaped from the application, almost all APC implementations result in numerous intangible benefits that cannot be represented in financial terms, yet result in noticeable improvement in aspects related to the process unit or plant operation. As an example, APC applications can dramatically improve the stability of the process, reduce operators' intervention, and improve flexibility of the process especially when switching to different modes of operation. The post audit report must highlight such intangible benefits and possibly present some before and after APC information as a measure of improvement.

C.3.1 Controller Performance

This is a measure of how well the controller satisfies its objectives. Statistical analysis measures (standard deviation, variance, and mean) as well as regulatory control measures (set point tracking, speed of response, etc.) can be used to describe this measure.

Controller and process information relevant to this measure may include items listed in Table C.1.

Table C.1 - Suggested APC Measures of Performance

Measure	Controller/Process Information
Tightness of control, controller stability, and tuning information.	Set point & Range tracking performance
Controller stability, smoothness, tuning, and model accuracy.	CV/MV movement
Controller speed of response, tightness of control, and disturbance rejection capabilities.	Closed loop Vs. open loop CV response
Performance improvements relative to pre-APC data.	CV/MV mean, variance, and std. dev.
Controller robustness, and plant operators confidence (intangible benefits).	Controller availability (service factor)
Quality of controller models.	Controller prediction error plot. However, it is necessary to distinguish between models inaccuracy and unmeasured disturbances when looking at prediction errors. Note: This information could also provide a benchmark for future post audit studies.

The post audit report shall highlight, whenever possible, the observed control performance improvements supported by process data plots and statistical data analysis for both the before and after APC scenarios. Sometimes, conducting a test-run for the controller is necessary to determine the performance improvement information and to verify whether the controller is able to satisfy its objective(s) or not.

C.3.2 Process Performance

This measure focuses on the controller's influence on the process behavior under APC. Products yield and quality information may give an indication to the tangible benefits of the APC controller. Statistical analysis tools can be used to identify the process performance improvement; however, the intangible benefits attained from the APC application also need to be highlighted in this measure. Process stability, flexibility, and operators intervention information are particularly important to highlight.

Other indications to the benefits from a process performance point of view are the optimization and constraints handling abilities of the controller. Collected process data need to show that the controller is driving the process to the optimum operating point as per the controller objective, and is riding the right constraints for the current mode of operation. For controllers with multiple modes of operation, a test run shall be conducted to test their performance in all modes unless the expense to the unit operation is too excessive.

Controller and process information relevant to this measure may include items listed in Table C.2.

Table C.2 - Process Performance Measures

Process Information	Indication
Active constraints	Control objective(s) fulfillment
Process operating point (CV/MV targets)	Controller optimization ability
Products yield information	APC tangible benefits
Quality control performance	APC tangible benefits
Energy and/or fuel consumption	APC tangible benefits
Process stability and ease of operation	Intangible process improvement
Level of operators intervention	Intangible process improvement

One may chose to combine both the control performance and process performance measures together when conducting the post audit study. The combined measure then shall present all the tangible and intangible benefits attained by the APC application.

C.3.3 Economic Performance

This measure represents both control and process tangible performance improvements in financial terms. It is often the strongest indication of the profitability of an APC project. Deriving the financial benefits can sometimes be straightforward. For example when control and process performance measures indicate increased yield of valuable products, increased unit conversion, reduced quality (specification) giveaway, or reduced energy consumption; then in this case converting such data into profit or savings information in financial terms is relatively easy.

However, sometimes it is necessary to analyze the controller's cost variables, as well as CV/MV movements and represent them in financial terms. The post audit report must explain the methodology followed in developing the economic performance measures and the basis of deriving the financial information. Pricing information used in the report shall be developed as per the directions and guidelines followed by Planning and Economics organizations at the facility. Controller and process information relevant to this measure may include items listed in Table C.3.

Table C.3 - Economic Performance Measures

Process Information	Indication
Increased yield of valuable products	Profit
Increased conversion	Profit
Increased throughput	Profit
Reduced quality giveaway	Savings
Reduced energy consumption	Savings

C.4 Inferential models and regulatory control performance

Since the inferential properties and the regulatory loops are essential to the APC application, the post audit report shall provide an indication about the performance of the inferential models (if any) and the regulatory control loops during the evaluation period.

The performance of the inferential models could be analyzed through a comparative study between lab analysis values and/or analyzer readings, and the inferential models output. Lab or analyzer bias update need to be examined during the post audit period by observing bias update trends to identify any model errors or drifts.

The performance of the regulatory control layer needs to be addressed briefly in the report. Poor performing loops need to be highlighted, tuning and remediation efforts need to be included in the report for action and future reference.

C.5 Post Audit Report Outline

Table C.4 contains a list of sections that a post audit report should have.

Table C.4 - Post-Audit Report Sections

Section No.	Title	Description
1	Executive summary	This section contains a brief synopsis of the study results for Plant and P&CSD management.
2	Overview	This includes an overview of the process, project scope, cost and schedule, as well as the controller scope summary.
3	Methodology	A discussion of the methodology used for the study including rationale for data selection and selected economic basis.
4	APC performance measures	This should include both control and process performance measures as a result of APC implementation. Regulatory control and inferential models performance could be included in this section.
5	Benefits calculations	This section shall include the economic performance information and includes all data, assumptions and calculations used to support the study conclusions. Benefit calculations should be provided in physical units and in monetary terms when economic data is available.
6	Observations	This section should explain both the positive and negative aspects of the project. Specifically, it should address how the project is capturing benefits. Areas where benefits are unrealized need to be presented with possible causes and recommended solutions. Intangible benefits could be highlighted in this section. Difference between study findings and project expectations can also be reported and explained in this section.
7	Future opportunities	This section identifies areas where benefits can be increased. Additional instrumentation, analyzers, process modifications, etc., may be included in this section.
8	Conclusions	This section should be a brief summary of the results and recommendations, as well as future areas of improvement.