

Guide to Advanced Control Systems

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Guide to Advanced Control Systems

1 General

1.1 Introduction

This Recommended Practice (RP) addresses the implementation and ownership of advanced control systems for petroleum processing facilities. The major sections of this RP are described in 1.2.2 through 1.2.7.

Figure 1 illustrates the major functions involved in the efficient and economic operation of a refinery and shows where advanced control fits into this scheme. Advanced control systems form a fundamental building block on which many of the other functions depend. Similar function charts would be applicable to other types of continuous processing facilities. Similar function charts would be applicable to other types of continuous processing facilities.

1.2 Scope

1.2.1 General

This RP describes commonly used practices for the opportunity identification, justification, project management, implementation, and maintenance of advanced control systems. This practice is not intended to specify the use or selection of any particular technique over another, nor is intended to describe specific applications. It may be used as the basis for defining the work processes and common functions required to define, implement, and maintain advanced control systems.

The practices described in this document are applicable to all advanced control systems applications. Users who are experienced in advanced control may have developed their own equivalent practices. This document is not intended to supersede user practices that have been found to be acceptable or to require that the practices described in this document be followed if they are not appropriate to the circumstance.

Selection of a specific hardware platform, software platform, or application software is not within the scope of this RP

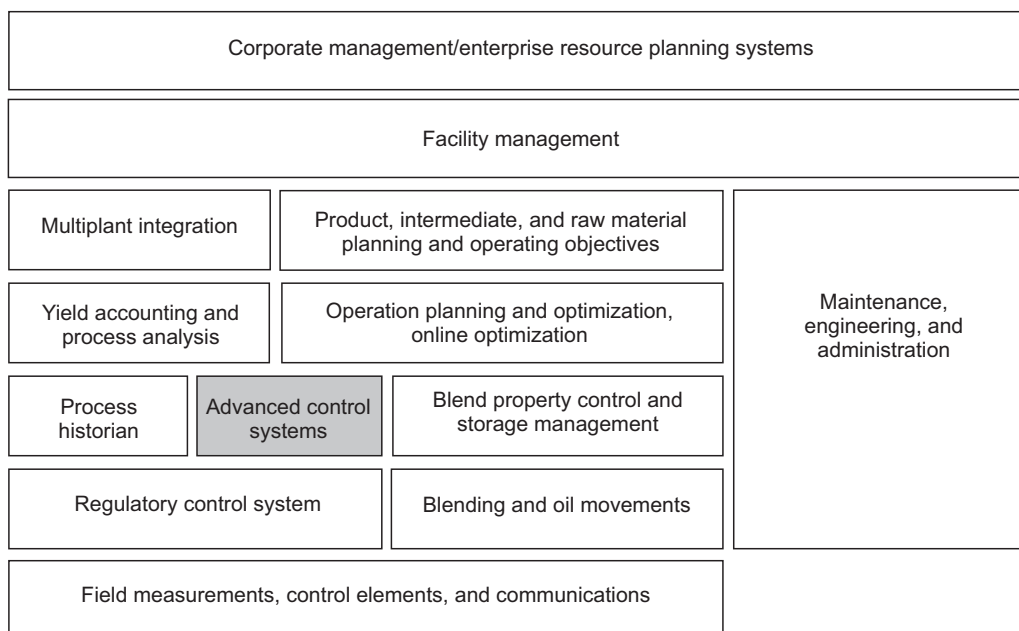


Figure 1—Refinery Operation Functions

1.2.2 Control Systems Functions and Types

The functions and characteristics of commonly used advanced control systems applications are described in Section 3.

1.2.3 Opportunity Identification and Justification

General procedures for identification of advanced control systems applications that may provide economic or operational benefit to a facility are described in Section 4.

1.2.4 Advanced Control Projects

General concepts for planning and management of an advanced control project are described in Section 5.

1.2.5 Technology Considerations

The technical issues that should be considered in selecting advanced control system hardware and software are described in Section 6.

1.2.6 Design Considerations

Application design features needed to support control functions, operator interfaces, and engineer interfaces are described in Section 7.

1.2.7 Application Maintenance

Ongoing maintenance recommended practices for advanced control systems are described in Section 8.

2 Terms and Definitions

For the purposes of this document, the following definitions apply. Also refer to API 554, (all parts) *Process Control Systems* for definitions of related terms.

2.1 Personnel

2.1.1

advanced control engineering specialist

An individual trained and experienced in the design and implementation of advanced control systems. This individual is knowledgeable in process engineering, process control theory and application, and computer applications. An advanced control engineering specialist may be an employee of a refining company, an employee of a control systems manufacturer or consultant, an independent consultant, or other contractor.

2.1.2

advanced control support specialist

An individual charged with monitoring and maintaining an existing advanced control application. This individual may be a unit process engineer, a plant control system engineer, or other individual who is knowledgeable in the specific application.

2.1.3

advanced control user

An individual who is the ultimate user of an advanced control system application. This individual may be a process operator or an engineer charged with operation of the advanced control system application.

2.1.4

operator

A person or persons that is responsible for day-to-day operation of a process unit and its advanced control applications.

2.1.5

project engineer

An individual responsible for the execution of an advanced control project. This individual may have a variety of responsibilities depending on the nature and scope of a particular project. Primary among these is management of the project resources, budget, and schedule. On smaller projects, an advanced control engineering specialist may also perform the duties of the project engineer.

2.1.6

unit engineer

An engineer (typically a process engineer) who is charged with engineering tasks directly associated with the day to day operation of a process unit or area. In some cases, this engineer may also be assigned the duties of an advanced control support specialist.

2.2 Controller Types

2.2.1

advanced control system

Any control system that has functions beyond those commonly associated with regulatory control systems. An advanced control system may be characterized by any of the following:

- a) a control system that controls or manipulates multiple variables in order to maintain one or more operating objectives,
- b) a control system that performs calculations beyond those that could normally be performed using standard algorithms available in process control systems,
- c) a control system that may utilize a significant number of process control system standard algorithms connected together in a complex manner.

NOTE Advanced control system may be implemented in either 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.

These types of applications are referred to by terms such as advanced process control, model-based predictive control, matrix control, and multivariable control.

2.2.2

controller

The collection of functions associated with either a regulatory control system or an advanced control system. In the context of this document, controller used without any other description is intended to mean an advanced control system.

2.2.3

multivariable control

A form of an advanced control system application in which several control variables (CVs) are maintained at desired values through a complex relationship. Several manipulated variables (MVs) may be adjusted simultaneously in order to maintain an economic or other operating objective. Multivariable controllers typically execute at a frequency of one to five minutes, although faster rates are also achievable.

2.2.4

optimization

A process control function that determines the operating conditions that maximize the economic benefit of an operation within a set of constraints. An optimization scheme may address any number of objectives such as

maximization of a particular product stream, minimization of operating cost, or maximization of an equipment item's operating life. Typically, optimization programs update operational targets at a frequency of hours to days and take into account the frequency of changes in the economic drivers at each site.

2.2.5

regulatory control

A control application in which generally one controlled variable is maintained at a desired value by adjusting one MV. 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.

2.3 Controller Terminology

2.3.1

advanced control system

The combination of the hardware platform, software platform, and application software necessary to implement an advanced control system application.

2.3.2

automatic shedding

A function by which an advanced control system application fully or partially turns off and control is returned to the regulatory control scheme. This may be a result of invalid input values, inability to deliver controller outputs, or inability of the controller to meet its objectives.

2.3.3

constraints

Limits in the process or equipment that should not be exceeded. (Sometimes referred to as "limit variables.") Constraints may take the form of physical limits such as a design temperature or pressure or other predefined process limits such as a maximum feed rate, composition, or other value. Constraints may be either maximum values or minimum values such as flow pressure, temperature, or process stream qualities. Constraints should be consistent with the HAZOP and alert/alarm strategy for the area being controlled.

2.3.4

controlled variables

CVs

Process values that are maintained by the control system by making appropriate adjustments to MVs.

2.3.5

disturbance variables

DVs

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 DVs change. Examples are ambient temperature, feed from another unit, etc.

2.3.6

linear program

LP

An algebraic computation optimization technique that uses two or more linear equations that relate process or economic variables. The LP solves the relationship to maximize or minimize the objective function that is usually an economic measure of operating efficiency.

2.3.7

manipulated variables

MVs

Process values that are adjusted by the advanced control system application to meet operating targets and desired values of controlled variables.

2.3.8**OPC server function**

Refers to open data interchange functions that are based on standards developed and maintained by the OPC Foundation.

2.3.9**process variable****PV**

An indication of process performance, which is directly measured using instrumentation sensors and transmitters, values that are computed from these variables or values obtained from laboratory testing or other techniques.

2.3.10**service factor**

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 on the numbers and types of subfunctions within an application, the percentage of time that the functions are operating and the relative economic weighting of each subfunction.

2.3.11**setpoint****SP**

An input variable that sets the desired value of the controlled variable; may be manually set, automatically set, or programmed. Its value is expressed in the same units as the controlled variable.

3 Control System Functions and Types

3.1 General

This section describes functions common to advanced control and related systems. Figure 2 illustrates basic control system functions and how they relate to this and other RPs.

3.2 Regulatory Control System Functions

Regulatory control systems provide fundamental control of process variables such as pressure, temperature, flow, and level by manipulating final control elements such as control valves or electric motors. The standard control algorithm used in these systems is proportional-integral-derivative, although alternate algorithms and calculations may also be used. The functions of regulatory control systems are covered in API 554, Part 1.

Complex regulatory control systems typically combine a number of functions used in regulatory control systems to meet a control objective. Typical applications include:

- cascade control,
- dynamic compensation (e.g. filtering or time-shifting of variables),
- variable gain adaptive controllers or other nonlinear algorithms,
- calculated variables such as pressure and temperature compensation of flow or other simple computations,
- override control using output selectors,
- ratio controllers.

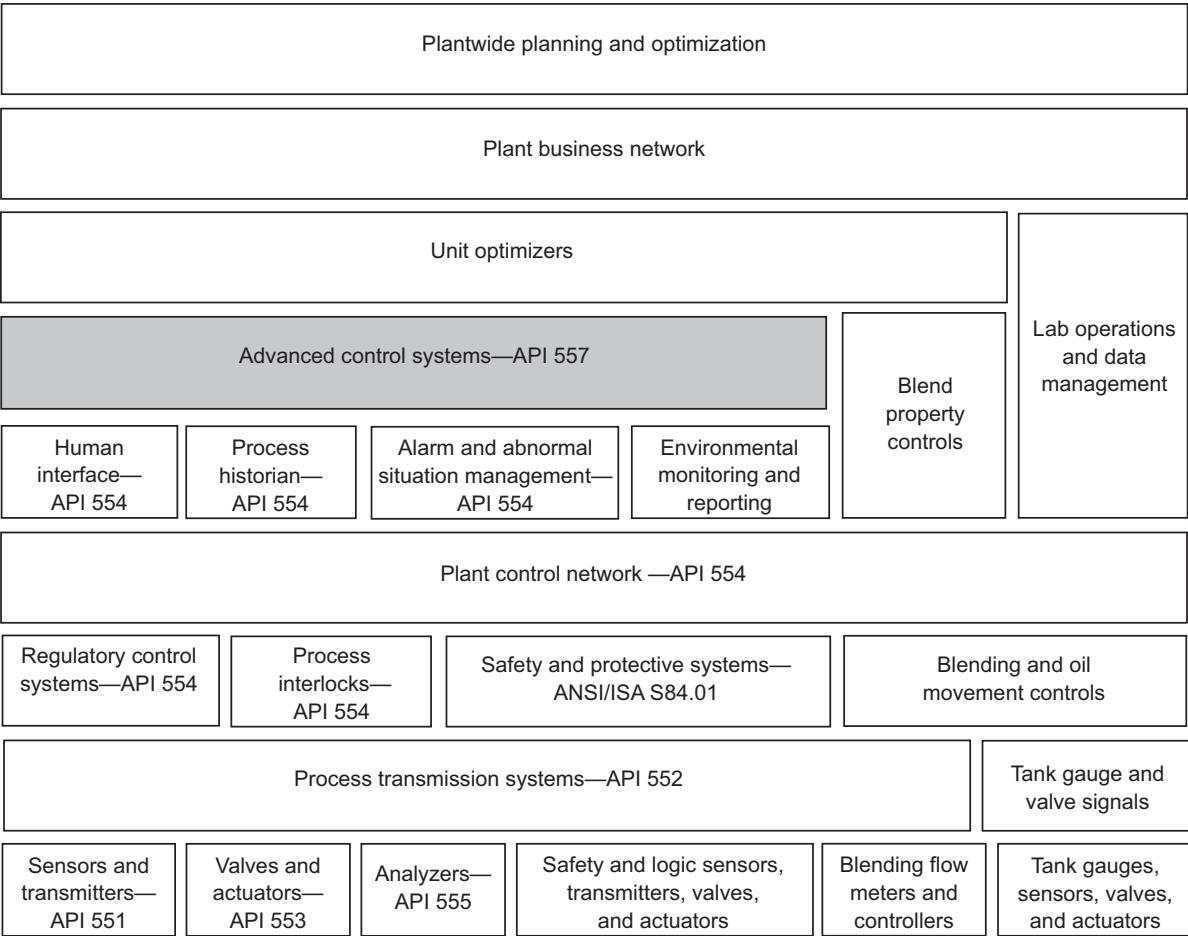


Figure 2—Control and Automation Functions

The regulatory control system should be configured to allow remote access to its setpoints so the advanced control system can write to them. It should also have a mechanism to automatically disable these remote setpoints or go to a predetermined status if the advanced control system has failed or is turned off. The reason for the failure or discontinued use should be captured at the time of occurrence.

3.3 Model-based Control Systems

3.3.1 General

Model-based control systems use a mathematical model of the process to improve process performance. The model may be based on process engineering principles or developed from empirical data collected from the process. These methods are described below.

3.3.2 First Principle Model-based Advanced Control Systems

First principle models are derived from the fundamental mass and energy balances and associated thermodynamics, equilibrium, and reaction kinetic relationships. These models can be used to improve control system accuracy or range when the characteristics of the process are well understood. Typical applications are:

- computation of heat and material balances or reactor yields and conversions,

- computation of inferred process variables that are not measured,
- improvement of control system operating range by including nonlinear effects.

First principle models typically are steady state relationships and become difficult to apply in processes that exhibit complex or variable dynamic behavior. One of the challenges with such models is the determination of the “values” to determine the relationships. Process unit meters are not meant to be custody transfer quality. Consideration should be given to “inferring flows and qualities.”

3.3.3 System Response Based Advanced Control Systems

3.3.3.1 General

System response models are based on observations of actual system dynamic performance. They are usually applied when a process is too complex to use first principle models or when multiple interacting variables are to be controlled. Common characteristics are:

- the control system is capable of performing multivariable control,
- the model is generally used to predict the effects of control moves and determine the proper actions,
- the controller handles constraints,
- the controller can optimize performance within the definitions available in the process model.

The system model allows the controllers to relate multiple manipulated variables (MVs) that the controller adjusts and multiple disturbance variables (DVs) that the controller cannot adjust to multiple CVs. It simultaneously adjusts all MVs to drive all CVs to their “best” operating points.

The process models determine the “best” operating point based on user-defined constraints and process economic information. Typically, the best operating point is where the maximum number of system constraints possible is reached. Figure 3 shows the general relationships of operating points and constraints. This is a simplified presentation, as in most real applications, multiple operating values and constraints exist.

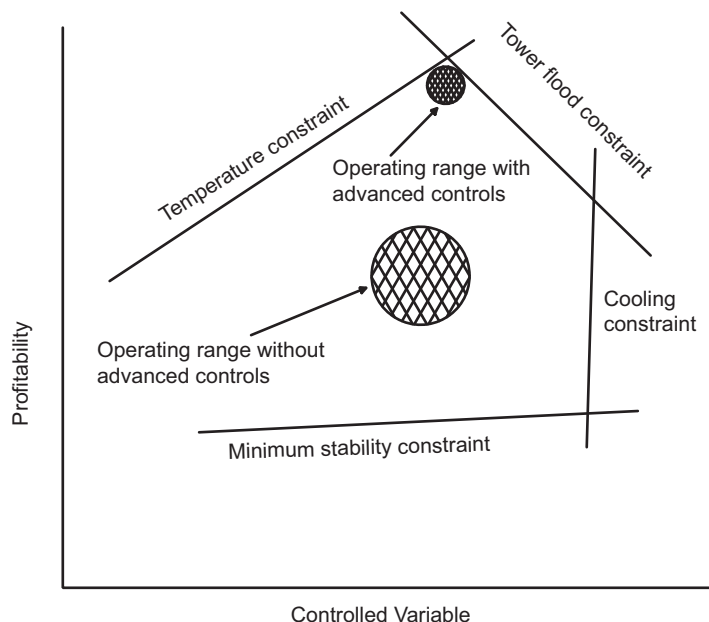


Figure 3—Operating Conditions vs Constraints

3.3.3.2 Multivariable, Matrix Based Systems

These systems use empirical models obtained by testing the process to identify its characteristics and interrelationships. Matrix controllers use linear models to relate MVs and DVs to CVs. They may also incorporate transformations of inputs and outputs to handle process nonlinearities. Some versions of these controllers have been extended to use nonlinear models. These controllers have been used in the industry for many years and have evolved considerably. In fact, they have improved to the point where the console operator's span of control has reached its horizontal limits.

3.3.3.3 Neural Net Systems

Neural networks are capable of providing similar functionality as matrix controllers. The fundamental difference between neural net and matrix controllers is a learning engine that develops the process model based on observations. The learning engine behaves somewhat like an optimizer that combines observations and user-supplied rules to generate a process model.

Neural net controllers require sufficient "good" process historical data to create a model. If such data is not available, a data acquisition period will be required.

Neural net controllers can produce nonlinear models and can adapt the model to process changes without requiring formal process testing. Typically, these adaptations are performed offline using parameters generated by the online neural net application.

3.4 Optimizers

3.4.1 General

Optimizers provide a computation method to determine the "best" operating point based on user-defined economic objectives and a model of the process. Typically, optimization programs update operational targets at a frequency of hours to days and take into account the frequency of changes in the economic drivers at each site. The outputs of optimizers are usually steady state objectives for other controllers such as multivariable controllers that handle dynamic control.

Optimizers may operate in an offline or online mode. In the offline mode the model is not receiving dynamic data from the process. In the online mode key real-time process data is connected to the model.

An online mode application may be online open loop or online closed loop. In online closed-loop mode, the outputs are automatically passed to the dynamic controls. In online open-loop mode, the optimizer outputs are presented to the operator, and the operator is responsible for passing changes to the dynamic control.

In online applications, significant data validation and reconciliation are necessary. It may also be necessary that steady operations exist when the optimizer is run. Some more powerful optimizers may not require this.

3.4.2 Imbedded Linear Programs (LPs)

Many multivariable controllers contain an imbedded LP to solve an optimization problem. The imbedded LPs are based on linear relationships between CVs, MVs, and the economic benefit or penalty associated with each variable expressed as a cost or benefit.

3.4.3 Unit Level Online Optimizers

Unit level optimizers may be used to compute operating targets for one or more unit multivariable controllers. These optimizers typically use a much larger number of variables and may have thermodynamic, equilibrium, or kinetic relationships built into them. They usually require functions for data validation, reconciliation, and parameter

estimation. Unit level optimizers typically are able to access economic data from external sources. Unit optimizers may use more rigorous nonlinear models to identify optimum operating conditions for the overall unit.

3.4.4 Plantwide Optimizers

Linking several unit level optimizers allows the system to locate a global optimum for the entire plant. In practice this is an extremely complex undertaking. This type of optimization requires rigorous models to ensure accurate results. Data reconciliation with overall material balances and yield accounting systems is a critical requirement for plant level optimizers. For example, as the product slate from one unit is the feed to the next, a small error introduced due to a poor model or conflicting data will propagate throughout the entire optimizer, which can provide an inferior result.

Use of these optimizers has often been limited by the accuracy of the unit optimizers when applied to very large systems. The computing load for these optimizers and the volume of input data can be immense. Some success has been obtained using offline LP models of a number of plants.

3.5 Expert Systems

Rule based systems are used where predetermined events exist. They are well suited for providing detailed information to operations based on events that have occurred in the process. Typically, these systems are used in an advisory capacity and are not directly connected to a control system. Abnormal Situation Management is an emerging application of expert systems.

3.6 Fuzzy Logic Systems

Fuzzy logic is used when the rules followed are inexact. It is a technique that can transform graded or qualified rules, such as if a “temperature gets too hot then slowly increase the cooling water,” into specific actions. Fuzzy controllers are a developing technology in the process industries. Fuzzy controllers may be imbedded in equipment controllers provided with packages. Some process control systems provide fuzzy control blocks as part of their algorithm set.

3.7 Batch and Sequence Systems

These control strategies are used for operations that have finite steps executed in a predetermined order. Some examples include reformer regeneration, water treating, and coke handling. These operations are described in detail in ISA S88.01 and are not within the scope of this RP.

3.8 Blending Systems

Component blending is used in various fuel production complexes. These systems are comprised of blend ratio regulatory control elements, property estimators, and optimizers that adjust recipes to meet final property specifications. The control systems used include advanced strategies as described in this document, but blending practices are not within the scope of this RP.

3.9 Oil Movement Systems

Oil movement systems use heuristic rule-based systems and are not within the scope of this RP.

3.10 Manufacturing Execution System

An application that is directed towards management of manufacturing operations. This includes issues such as manufacturing scheduling, raw material management, and resource planning. The application typically resides at the business network level and is outside the scope of this document.

4 Opportunity Identification and Justification

4.1 Resource Requirements

The identification of improved control opportunities is a multidisciplinary task with incremental economics, statistical data reconciliation, operations planning (including scheduling and dispatching), operations, process, and control application knowledge and experience playing the most significant roles. Experience has demonstrated that the essential element of success in implementing advanced control projects is the engineers' knowledge, experience, and ability. While appropriate technology is an important factor, it cannot make up for lack of skill or experience in the personnel implementing, maintaining, and using the application.

A benefits feasibility study for a single process advanced control application can be handled by a suitably skilled individual relying on specialist support where required. However, as the scope of the study increases, particularly when studying a complete facility, a small mixed discipline team approach is recommended. The team should include representation from site process/planning, operations, and control system engineering.

Benefit identification requires both technical and interpersonal communication skills. Identification and realization of benefits requires:

- a) understanding the economic driving forces for the processes (e.g. the incremental process and energy economics and the timing of the changes to those values);
- b) understanding how the processes work and interact;
- c) understanding the process's real limitations and constraints;
- d) obtaining buy-in for the benefits and solutions from the advanced control users and business support specialists (e.g. budget planners, schedulers, and economists).

4.2 Economic Drivers

Long- and short-range business plans should be the basis for evaluating potential benefits. These plans should reflect the impact of a number of typical economic drivers. Not all of them will be applicable to a particular market or facility, but they are indicative of the forces that determine the economics. Examples of economic drivers that should be considered are as follows.

- Business management drivers:
 - financial objectives,
 - environmental and safety objectives,
 - process unit turnaround schedules.
- Local plant drivers:
 - feedstocks and finished product pricing;
 - volume and shipping methods for crude and other feedstock;
 - demand and shipping method of finished products;
 - product margins;