ADVANCED PROCESS CONTROL AND OPTIMIZATION SOLUTIONS

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This paper reports the advanced control and optimization solutions which Yokogawa Electric Corporation has developed. More than 200 projects applying these solutions have already been implemented, and have been operational on-site in the global market since their release in 2000. Exarqe, our online quality estimator, estimates the properties of influents and products. From the control of a single process unit to plant wide operation, Examoc's multi-variable predictive optimizing function maintains specifications for plant conditions to realize peak production and maximize profits. Exapot, an online real-time optimizer with monitoring and diagnostic functions constantly monitors control and optimization functions to improve control operations. By integrating these solutions into plant operations, pivotal issues such as stability, safety and environmental impact will be resolved.

INTRODUCTION

In 2000, we formed a technical tie-up with Shell Global Solutions (SGSI) to enter the advanced process control and optimization solution business. At the same time, we started marketing a solution based package comprising an Exasmoc multi-variable model-based predictive control function, an Exarqe property estimation function, an Exaspot online real-time optimizer and an MD control monitor & diagnosis function by taking full advantage of the SGSI advanced control and optimization technology (APC&O). Thanks to the partnership with SGSI which enables us to market the results of 800 or more projects developed in actual sites by SGSI and to build our unchallenged position as a solution vendor, we have already sold 200 systems all over the world as of the end of 2005. In 2006, we officially released Exasmoc/Exarqe R3.04, which allows the system to handle large-scale, complicated plants such as ethylene plants and ultra-deep-hydrodesulfurization plants. This report outlines the above functions from the viewpoint of solutions to users.

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PURPOSE OF APC&O INSTALLATION

Advanced process control and optimization technologies are applied to industrial processes for the following purposes:

- To increase operating profits and operational efficiency by maximizing the throughput under operational and safety restrictions
- To reduce operation loss by squeezing the variation of main variables and pushing them to operational constraints
- To improve safety by ensuring the respective process units are in a safe condition
- To reduce maintenance and utility costs

Figure 1 shows a typical configuration of APC&O solutions based on our solution based package (SBP).

QUALITY ESTIMATION SOLUTION

Methods called “soft sensor” and “virtual analyzer” are widely used for the real time estimation of qualities of the raw material or product compositions directly from the scanned process flow, temperature and pressure. In the refineries and petrochemical industries, this solution is used to estimate an ignition point, lead steam pressure, octane number, melt index (molecular mass) or density. This not only reduces the analysis time delay on an analyzer but also provides the improvement of

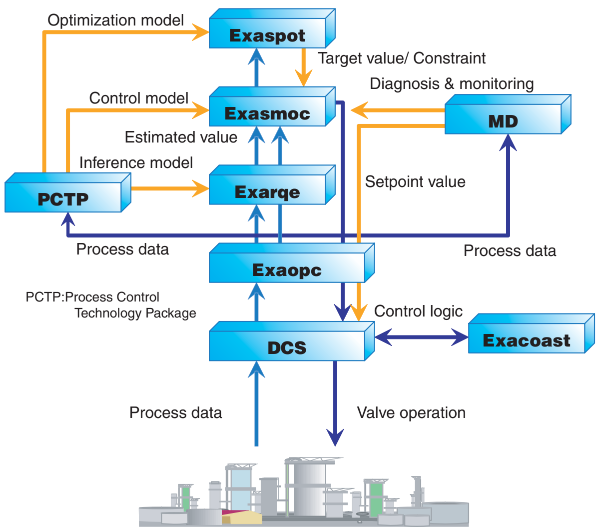


Figure 1 Solutions Using an SBP Package

advanced control. In a solution using Exarqe, the following functions ensure high-precision, robust estimation of properties:

- Estimating an intermediate property value from input/output data once and reusing the data for multi-stage estimation
- Estimating qualities of multiple components in a pipe or tank simultaneously
- Calibrating an estimated value intermittently by using sampled laboratory data
- Executing the blend correction function and calculating tank property value for estimation

In addition, the following functions are prepared for the Exarqe online use:

- The linear regression method using PLS (principal component analysis) or PCR (partial least squares) or RBF-based neural network method can be selected.
- OPC interface server/client functions allow connection to the software or DCS products of any vendors.
- The model configuration tool and simulation tool make it possible to tune an estimation model or to simulate a transient state of the property.
- The estimated property values can be utilized as an APC or DCS control loop setpoint value.

Figure 2 shows an example of estimating property values by Exarqe. Graphs represent the measured values, estimated values and model errors respectively. The first half of the data is used for training on model creation and the second half for verification.

In an application example in aromatic plants, as the influences of sampling cycles with conventional analysis instruments or of piping delays have been eliminated, the estimated value can be measured online and the toluene density can be prevented from violating the constraints.

MULTI-VARIABLE MODEL PREDICTIVE CONTROL SOLUTION

Multi-variable model predictive control predicts a few step

Figure 2 Example of Property Value Estimation by Exarqe

ahead behavior of the target process for control, assuming it to be of a MIMO (multiple input multiple output) model. The controller not only keeps the control variables within the setpoint range, but also maximizes or minimizes the control objective function or maintains the input and output constraint condition, using the degree of freedom which is the difference between the number of outputs (MV) and inputs (CV). To provide the above control, the following technologies are implemented:

- Essentially, decoupling control, dead time compensation, feed forward control and observer functions have been implemented to establish a stable control system.
- The controller can be configured hierarchically (main controller/subcontroller configuration) to provide a consistent control architecture over small- to large-scale processes. In addition, priority can be set among control variables.
- The online gain setting and bilinear objective function are provided to cope with the process non-linearity and time-variant.
- Data exchange via the OPC interface, screen build using ActiveX components, and configuration data file formatted on XML are provided to connect with other vendors' DCS or other solutions.

Some typical applications are outlined below.

(1) Debutanizer

This application is typical in a 2-component separation process in a petroleum or petrochemical plant. A common issue in distillation tower control is that the operating conditions vary due to mutual interference between components at the top and bottom of a tower, a tower having a large time constant, a non-linear behavior, a feed flow change or a feed composition change. It is therefore necessary not only to maintain the properties of the C5 component from the tower top and C4 component from the tower bottom but also to minimize the upper limit of loading in the tower and the amount of energy of the reboiler. Thanks to the above functions, Exasmoc can solve all of these issues.

(2) FCC fluid catalytic cracking process

The purposes of FCC unit operations are to maximize both the amount of charge and rate of conversion to high-value added products so that the total production quantity becomes maximized. To do this, the temperature of the reactor is kept high and stable, the pressure within the tower is minimized and the catalyst circulation rate is increased. As a result, the product (gas) quality is kept stable and operator intervention is reduced. Solutions using Exasmoc use multiple sub-controllers to control the reaction-reproduction tower and main distillation tower, and a main controller to maximize the total throughput. Investment can be recovered within six months to one year.

(3) Ethylene process

An ethylene plant generally consists of multiple cracking furnaces, demetaniser, deethanozer, depropaniser, debutaniser, C2 distillation column, C3 distillation column, C4 reactor and quench tower, each of them are controlled by each corresponding sub-controller. The purposes of ethylene plant operation are to maintain the severity balance (described later) of a cracking furnace, maximize the throughput under the operational constraints of the cracking furnace and maximize the ethylene or propylene profitability in the fractionating column. In the cracking furnace control keeping the methane/propylene ratio (severity) constant is a key to maintain the amount of ethylene or propylene gas to be produced. To ensure this, the coil exit flow and pressure are manipulated. To obtain a high purity of product (gas) in the C2 and C3 rectification towers, the amount of extraction, reflux flow and tower top pressure are controlled. The same control (1) takes place in the demethaniser, deethaniser and depropaniser respectively. In these columns the controller manipulates the column draw rate and reflux flow aiming to keep each olefin product at the target specification, while maximizing its recovery.

ONLINE OPTIMIZATION SOLUTIONS

The online real-time optimizer collects process operation data periodically at first. Using the embedded process unit model based on material balance, energy balance, heat balance and so on, it computes the optimal operation points to maximize the profit, and then downloads them to the lower level controllers such as model predictive controllers and PID controllers in DCS. Various data such as profit trend, profit tolerance, profit factor analysis and mass balance are provided to operators and/or operation engineers for use to monitor the process performance condition or support decision-making. The following technologies are implemented for this purpose:

- A process model is configured using a flow sheet based builder. As the configured model is executed sequentially, it makes easy to analyze the optimization procedure.
- The online real-time optimizer must have a scheme for consecutively executing steady state detection, periodic data collection, process unit configuration check and data reconciliation functions. Exaspot has implemented this scheme.
- As the system is composed using the Exaquantum plant information management server as its core, I/O data definition, setting of initial value and test data can be easily modified and changed using a spreadsheed based configuration tool.
- As industry de-facto standard interfaces such as OPC, WEB and OLAP are supported, it is easy to connect with PLCs and DCSs from other vendors.
- As the trial operation data and optimization calculation data are saved in a history data file, the operating conditions and optimal conditions can be analyzed offline later.

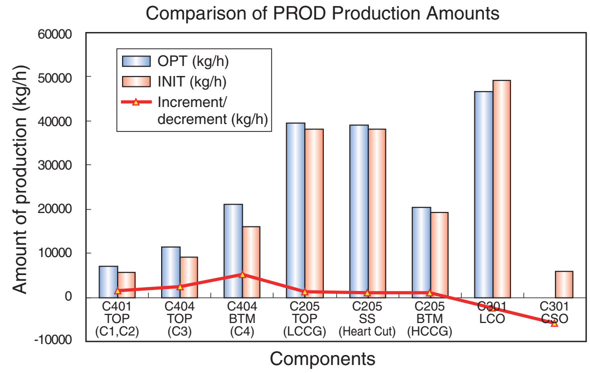


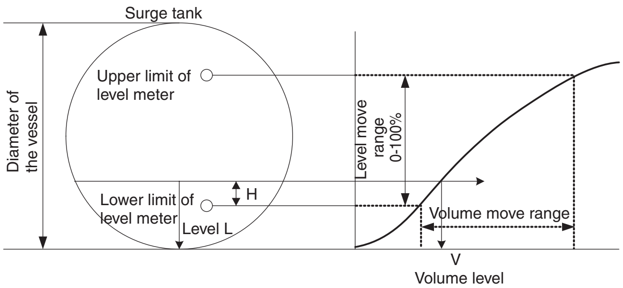
Figure 3 Example of Optimization Profit Factor Analysis

Figure 3 shows an example of optimizer application to an FCC plant. The optimizer shows an increase or decrease of each component as an index so that the operator can check the validity of the output from the optimizer. The polygraph shown in Figure 3 indicates that low price component production decreases and high price component production increases to the contrary.

FUNCTION BLOCK SOLUTION

Yokogawa Electric Corporation offers a control function for specialized applications based on Shell's rich experience over many years. It works as a function block of the field control station of our CENTUM DCS.

- Shell Surge Volume Controller (SSVC): The controller steadily controls the liquid level in a surge vessel and minimizes the output flow variation. Though the operation in the stationary mode is equivalent to that by integral PI control, the output flow is controlled to balance the input and output of the vessel in the out-of-limits level. Figure 4 shows the expression for converting a surge vessel liquid level to a volume based. In this case, however, the horizontal length of the vessel should be sufficiently longer than the diameter of the vessel D. Non-linear operation and control can be simplified through the above level-to-volume transformation.
- Furnace Pass Coil Balance: To maintain equal pass outlet temperatures for a furnace cell, the furnace temperature, cell temperature and pass in a cell temperature are balanced and the pass flow within the cell is calculated based on a pass temperature distribution. This calculation is required because heat transfer to the individual passes in a cell varies depending on the asymmetric frame patterns, different burner characteristics and differences in fuel, steam and air flow.



$V = C_0 + C_1{*}H + C_2{*}H^2 + C_3{*}H^3$
V: Normalized fractional volume, H: Compensated level
C0 to C3: Coefficient

Figure 4 SSVC Level-to-Volume Conversion

Date	Control Performance: Comply	Not Comply	Off Ctl	Out Srv	Benefits: Realized	PONC
2005-01-03	35	38	27		$7,155	$3,721
2005-01-04	33	39	27		$7,154	$3,722
2005-01-05	36	36	27		$7,155	$3,721
2005-01-06	36	36	27		$7,150	$3,721
2005-01-07	37	36	27		$7,155	$3,721
2005-01-08	37	35	27		$7,155	$3,721
2005-01-09	37	35	27		$7,154	$3,722

Avg. Control Performance: Comply	Not Comply	Off Ctl	Out Srv	Avg. Benefits: Realized	PONC
36	36	27		$7,154	$3,721

*PONC:Price of Non-Conformance

Figure 5 Example of Operating Rate Display

- Column Tray Loading: Based on data such as temperature, pressure and liquid/vapor flow in each tray of the distillation column, tray shape and column/tray dimensions, the data effective for optimization in the respective tray is calculated, including the liquid flow load, vapor flow load, percentage of flood gas factor for weeping and sealing.
- Measurement Validation Comparison: The validity of signals from a transmitter is checked. In addition, when multiple transmitters are installed, the values of both transmitters can be compared to detect transmitter faults promptly. For this purpose, there are three check methods: General Measurement Check for parameter check, Validation check and Comparison check using a statistical method (CUSUM).

CONTROL MONITOR AND DIAGNOSIS SOLUTION

To maintain an APC operating rate after project completion, a performance indicator must be defined to always monitor the control performance. The control monitor diagnosis function defines the following statistics to continuously monitor whether or not the system is operating as expected.

- In Service (%): A time percentage is displayed to indicate the duration a control variable was in service and available. A controlled variable, loop, or a unit may be out-of-service when maintenance is being done. The more the availability of the process variable decreases, the less the observability of the process variable decreases and the more APC control merit is lost.
- Uptime (%): A time percentage is displayed to indicate the duration a particular control variable was operating in control mode. When the controller is operating in control mode, it means that the controllability is improved and the profitability also increases. In this state, even though the control is sometimes subject to be in manual operation by the operator, the controller can generally perform well.
- In Compliance (%): A operating time percent is displayed to indicate the duration a control variable is within in a user-specified range of upper and lower limits. This statistics indicates the controllability of the controller, which makes it possible to calculate the benefits of the controller.

Figure 5 shows a typical control monitor and diagnosis function view with the above index displayed by date. As the "comply" state percent of the control increases, the operating time percent (in service%) also increases. In addition, when these statistical data are is assigned a price unit, an APC operating rate can be converted to a benefit and used as an evaluation index for operation. ◆

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