Energy-saving Solutions by Advanced Process Control (APC) Technology

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Equipment for continuous processes such as petroleum refining consumes much energy, and various energy-saving activities have been carried out. In recent years, energy conservation is attracting attention globally as a solution for environmental issues. Advanced process control (APC) is one technology which has been greatly contributing to energy conservation. This report describes Yokogawa's activities relating to APC and its applications.

INTRODUCTION

In 1999, Yokogawa Electric Corporation formed an alliance with Shell Global Solutions International B.V. (SGSI) in Advanced Process Control (APC), and both companies have since jointly developed products. This alliance successfully combined SGSI's experience gained through more than 800 projects in more than 30 years and Yokogawa's great deal of experience with the process control market, and strengthened the scheme to provide the APC technology. Products developed by this technology alliance are listed below and as of 2009, more than 250 systems were in operation around the world.

1) Exasmoc: Multivariable Model Predictive Control Package
2) Exarqe: Online Robust Quality Estimator Package
3) Exaspot: Online Real Time Plant Optimization System
4) Exacoast: Control Function Blocks
5) PCTP (Process Control Technology Package):
   A package containing a group of functions such as the Exasmoc and Exarqe offline functions and control performance monitoring and diagnosis (MD) functions

The APC technology is usually introduced for the purpose of maximizing the profit by increasing the operation efficiency, and needless to say, its main purpose in many cases is to conserve energy, and it has provided solutions for many projects. Meanwhile, the fight against global warming is attracting attention as a global agenda, and efforts to conserve energy focusing on the reduction of CO_2 emissions are accelerating in all areas. The role to be played by the APC technology in the process control field will further increase in the future.

This report presents Yokogawa's activities relating to APC [(1)] and then describes application examples of APC from the perspective of energy conservation.

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WHAT IS APC?

Figure 1 explains what the APC is. The figure shows an example of achieving energy conservation by reducing the allowance as much as possible within the range not exceeding the operational limit which the target process has.

The period with large amplitudes on the left of the trend data in Figure 1 is the one during which APC is not activated (before APC is introduced). Basic control loops such as those for flowrate, temperature, level, and pressure are controlled during this period by systems such as a distributed control system (DCS), and the operator adjusts the setpoints manually to achieve targets such as that of energy conservation. Accordingly, the data usually varies significantly, so a large allowance is required against the operational limit in case unexpected changes occur during operation.

An introduction of APC capable of improving the control performance results in the reduction in the data variations as shown during the period in which APC is activated. A decrease in the data variations results in an increase in the gap between the fluctuating data and the operational limit, so optimization control makes it possible to bring the setpoint even closer to the operational limit as shown during the period in which the optimization control is activated.

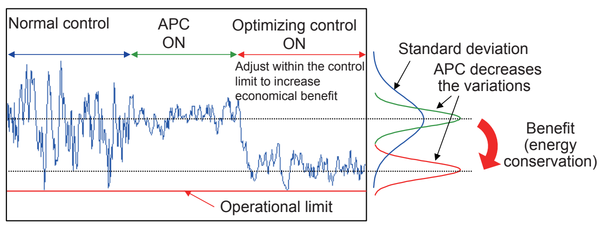

Figure 1 What is APC?

As described above, APC can be defined as a control that not only aims at improving control performance but also maximizing effects such as that of energy conservation by automatically bringing the operation closer to the optimization.

APC can also be easily applied to control aimed at not only increasing production and saving labor but also conserving energy as described above, so it has provided solutions for many projects.

YOKOGAWA's APC

Figure 2 shows a configuration example of APC products provided by Yokogawa. The light blue parts show APC products. This section provides an overview of the features and functions of these products.

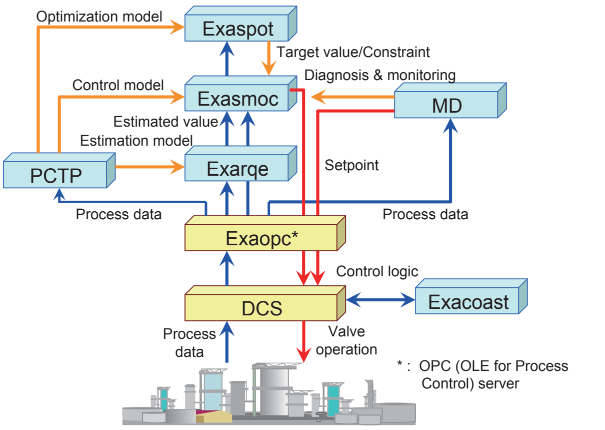

Figure 2 Example of Configuration of Yokogawa's APC Products

Multivariable Model Predictive Control Package (Exasmoc)

Exasmoc is a core product for implementing APC. [(2), (3)] As shown in Figure 3, Exasmoc represents the target process as a model with multiple input and multiple output, and performs control by predicting the behavior of the process several steps ahead. Manipulated variables (MVs) and disturbance variables (DVs) are input, and control variables (CVs) are output.

An Exasmoc controller is capable of maintaining the CVs within the predifined range, and able to maximize and minimize the objective function under various restriction conditions by using the degree of freedom owing to a difference between the number of outputs and the number of inputs (optimization function). Since the optimization function is embedded in the control algorithm, both improving of control performance and optimization can be achieved at the same time. Accordingly, at present, an introduction of APC means almost the same as an introduction of a multivariable model predictive control.

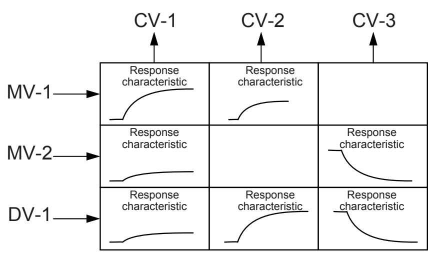

Figure 3 Prediction Model Conceptual Diagram

Online Robust Quality Estimator Package (Exarqe)

The control target should be controlled according to the quality control indicators, but there are many cases where proper process values that should be used as indicators are not measured online. Exarqe is able to estimate various process values that should be used as indicators online, so it has long been used to estimate the flash point, reid vapor pressure, octane value, melt index (resin fluidity), and density in oil and chemical industries. [(3)]

The delay in the analysis by the analyzer can be removed by using the online estimated data. Furthermore, Exarqe has a function to compensate (update) the estimated values using the values from the online analyzer and analysis results, so maintenance is not required for a long time. The control performance can also be improved by using these estimated values as shown in Figure 4.

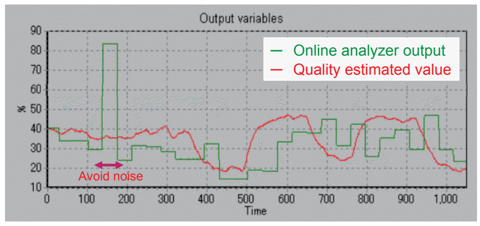

Figure 4 Example of Online Quality Estimation Results

Online Real Time Plant Optimization System (Exaspot)

Exaspot is used as an upper-layer function for the total optimization in large-scale complex processes in oil, chemical, or other industries. An example of a result of the total optimization correspond to a function, as shown in the example of Figure 2, which continuously optimizes the operational limit considering the constantly-changing situation. This function is needed to achieve energy conservation for large-scale processes such as that of an ethylene plant or for the whole plant.

Exaspot periodically collects operation data of the process, calculates the optimal operation setpoints from economical viewpoints such as a minimum cost operation by using an embedded process unit model based on material balance, heat balance, or other calculations, and provides the setpoints for the lower-layer Exasmoc controllers and PID control function blocks of the DCS.

Control Function Blocks (Exacoast)

Yokogawa makes the best use of SGSI's long-time experience and field-proven expertise to provide the application specific control functions described below as the function blocks of the field control stations of CENTUM which is Yokogawa's DCS.

1) Heating Furnace Pass Balance Control (ZBALANCE)
2) Distillation Column Tray Load Estimation (ZCTL)
3) Multiple Measurement Point Validation Function (ZMVC)
4) Uniform Flow Level Control (ZSSVC)

The following describes the function of the heating furnace pass balance control (ZBALANCE) that is expected to produce a great energy conservation effect.

A heating furnace consumes a lot of fuel, so control has the potential of producing a great energy conservation effect. As shown in Figure 5, ZBALANCE adjusts the flowrate of each pipe (pass) in the furnace and performs control so that the variations in the outlet temperatures are reduced.

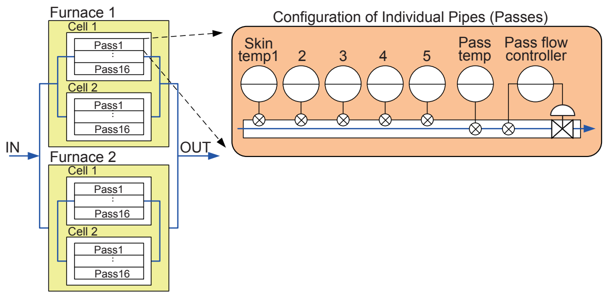

Figure 5 Heating Furnace Pass Balance Control (ZBALANCE) Conceptual Diagram

Since the heat transfer to multiple pipes generally differs by individual pipe because of non-uniform burning in the furnace or for other reasons, the outlet temperature of each pipe differs even when the flowrates of the pipes are identical. In many cases, this is not regarded as a problem from the perspective of safe operation. However, control that makes the outlet temperature of each pipe as uniform as possible results in the transfer of a large amount of heat through highly thermally efficient pipes, so a great energy conservation effect can be expected. Furthermore, a decrease in the variation in the temperatures makes it easy to control the upper limit of the skin temperatures (surface temperatures of the pipes), etc.

Control Performance Monitoring and Diagnosis (MD)

When introducing APC for the purpose of achieving an energy conservation effect, it is important to maintain its control performance. To do so, it is desirable to define indicators that can be monitored at all times. Since the operation rate of APC accurately reflects the degree at which the control action is accepted in the field, the control performance can be maintained by monitoring and diagnosing the operation rate.

MD calculates the following statistics as the operation rates.

- Comply
  Rate of time at which the control variable is within the expected range
- NotComply
  Rate of time at which the control variable is controlled but is not within the expected range
- Off Control
  Rate of time at which the control variable is not controlled
- Out Service
  Rate of time at which the control variable cannot be used because of maintenance, etc.

Figure 6 shows an example of an operation rate report that displays the above indicators in chronological order. This report can be sent via the Web. The higher the Comply rate in the figure, the higher the operation rate is, so the control performance can be determined to be higher. Furthermore, the heading entitled "Benefits" in the right half of the figure displays the benefits gained by energy conservation. These can be calculated based on the current operation status by defining the unit price for the above statistics.

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

Figure 6 Example of MD's Operation Rate Report

EXAMPLES OF APC APPLICATIONS FOR THE PURPOSE OF ENERGY CONSERVATION

Application Examples of Oil and Chemical Processes

The following shows examples of APC application for the purpose of energy conservation in oil and chemical processes. Control design for devices such as a fluid catalytic cracker (FCC) is actually often made on a process unit basis, but the following shows application examples on a device unit basis considering the possibility of deployment to other processes.

■ **Heating Furnace**

A heating furnace consumes a large amount of energy, so control for the purpose of energy conservation has long been performed in many projects. The following shows two typical examples.

- Pass Balance Control

As explained in the "Control Function Blocks (Exacoast)" section, decreasing the variation in the outlet temperatures of the pipes in the furnace produces great benefit from the perspective of energy conservation. Yokogawa has provided energy conservation solutions for many projects, including the ZBALANCE function described above.

- Exhaust Gas Oxygen Concentration Control

All air that is fed to the furnace along with the fuel is discharged as a needlessly heated exhaust gas except for the oxygen that is optimal for burning. Accordingly, monitoring the oxygen concentration in exhaust gases and performing control so that excess air is not fed to the furnace produces a great energy conservation effect. In cases such as that of a simple furnace, PID control is enough, whereas, in cases such as that in which multivariable control is needed to monitor the pressure inside the furnace at the same time, use of Exasmoc can be expected to produce a great energy conservation effect.

■ **Distillation Column**

A distillation column is one of the equipments that is very often used in oil and chemical processes and consumes a large amount of energy.

Since the interference between the column top and column bottom is strong, the time constant is long, and the behavior is nonlinear, it is very difficult to improve the control performance with a one-input and one-output control such as PID control, so priority is given to device stability over energy conservation in many cases of control.

However, APC combining Exasmoc and Exarqe enables design with the aim of implementing control for the purpose of not only stabilizing the device but also energy conservation by reducing the reboiler steam, the amount of reflux, and the column top pressure, etc. Accordingly, the target of many of the APC applications in oil and chemical processes is the distillation column and Yokogawa has provided solutions for many projects. Figure 7 shows an example of APC application for a distillation column.

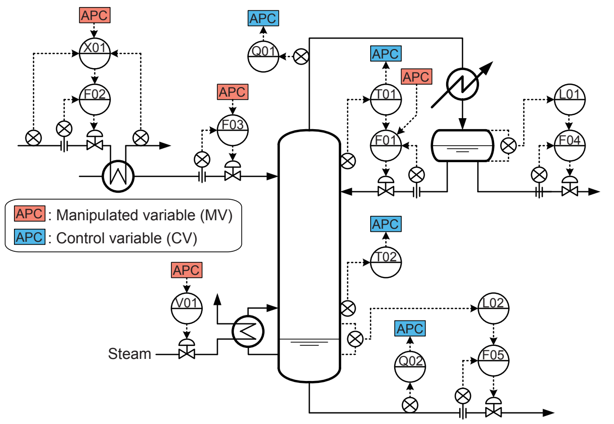

Figure 7 Example of APC Application for Distillation Column

■ **Reactor**

Many reactors such as those for continuous catalyst regeneration (CCR), FCC, and hydrogen desulfurization are used in not only chemical but also oil refinery processes. Operating reactors within the range close to the optimal reaction conditions with respect to the temperature, pressure, etc. produces the greatest energy conservation effect. Accordingly, as with the distillation column, an introduction of APC can implement control for the purpose of both stabilization and energy conservation. There are many similar reactor processes in oil refinery processes, and it is easy to accumulate knowledge, so there are many examples of APC applications for reactors.

■ **Compressor**

A large compressor consumes a large amount of power, so operation with minimum power consumption results in energy conservation. For example, operation at maximum capacity is required during the daytime in summer but the demand decreases during nighttime. Applying APC and continuously monitoring the demand prevents operation at excess capacity, resulting in energy conservation.

Application Examples in other Processes

Yokogawa provided the many APC solutions for various processes. The APC application for the heating furnaces and compressors described in the previous section are also found in many projects relating to processes other than oil and chemical processes. The following presents other typical examples.

■ **Utility Facilities (Boiler, Turbine, and Generator)**

Utility facilities supply steam and power to the plant, and operation with switching operation loads according to the power purchase prices result in power conservation. When the efficiency of a boiler and turbine is approximated linearly, Exasmoc's optimization function enables control to optimize the load according to the power purchase prices by its embedded linear programming.

■ **Electrolyzer**

An electrolyzer forms a process to consume a large amount of power. Since the electrolyzer is operated according to the power purchase prices over the course of the day, many disturbances are caused by operation changes and the dead time is long, so it is difficult to even stabilize the operation with the conventional control. In contrast, APC is able to perform stable control and reduce the power consumption simultaneously. The electrolyzer temperature is controlled so that it is brought as close as possible to the control limit.

CONCLUSION

APC has long and widely been used in continuous processes, including oil refinery processes, and has greatly contributed to energy conservation. APC that was presented here is not limited to large-scale continuous processes but has the potential of being widely applied to manufacturing equipment. In addition, introduction cost is decreasing year by year due to falling computer and hardware prices and increasing reliability. Although there are still many users who are hesitating APC introduction, we hope that this report will motivate them to think again about the introduction.

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