POWER Engineering

Coordinated Control and Optimization of a Complex Industrial Power Plant

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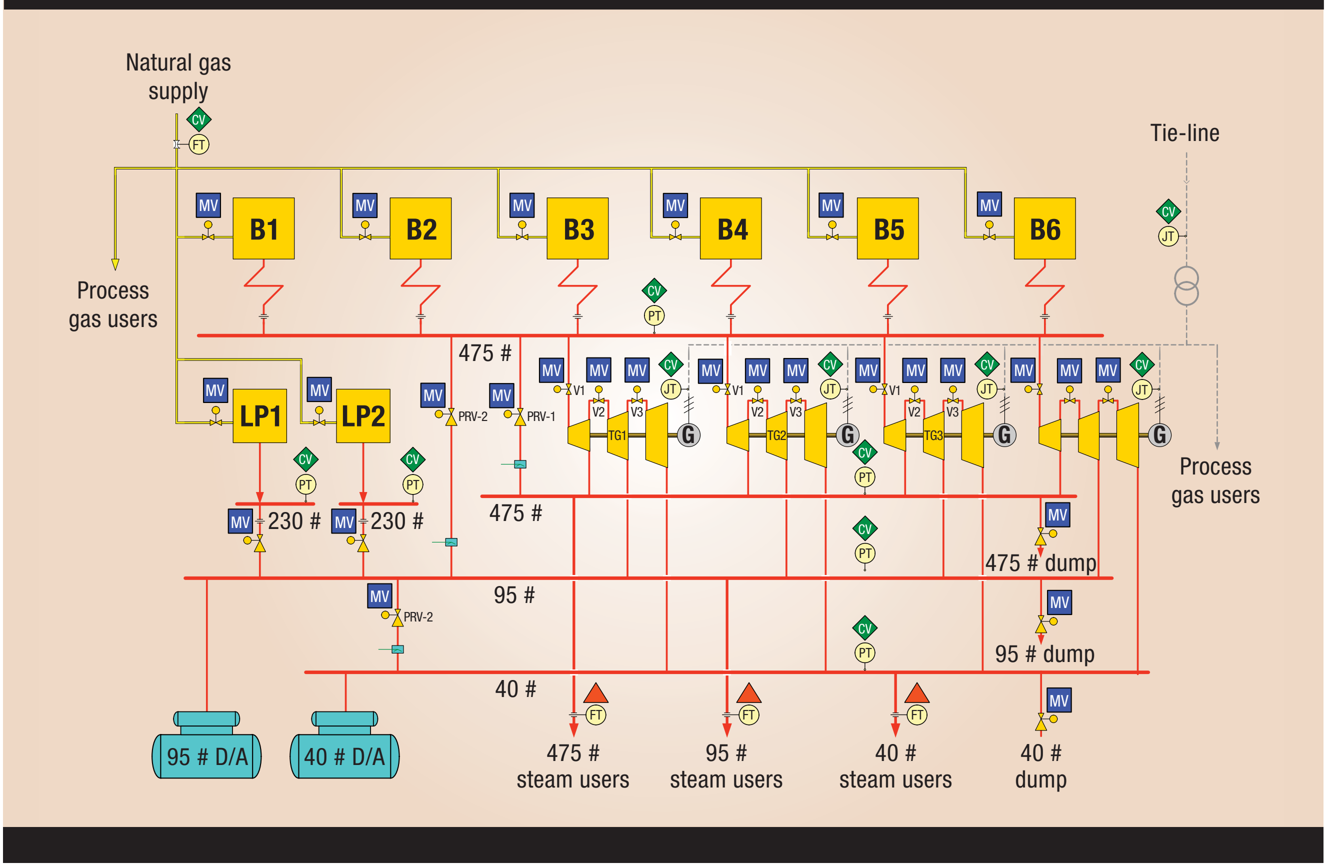
Alcoa World Alumina L.L.C. is one of the world's largest producers of metallurgical grade alumina, the raw material for the aluminum smelting process. The Point Comfort Operations is Alcoa's only alumina refinery in the U.S., with a production capability of 2.3 million tons a year. In the refinery, bauxite is converted to alumina through a Bayer refining process. This process consumes a large amount of energy, delivered in the form of electrical energy and steam. As energy costs in alumina refining typically represent 20 percent of the overall manufacturing cost, the Alcoa Point Comfort Power Plant is an important element in the refinery's economic performance.

Figure 1 ALCOA POINT COMFORT POWER PLANT



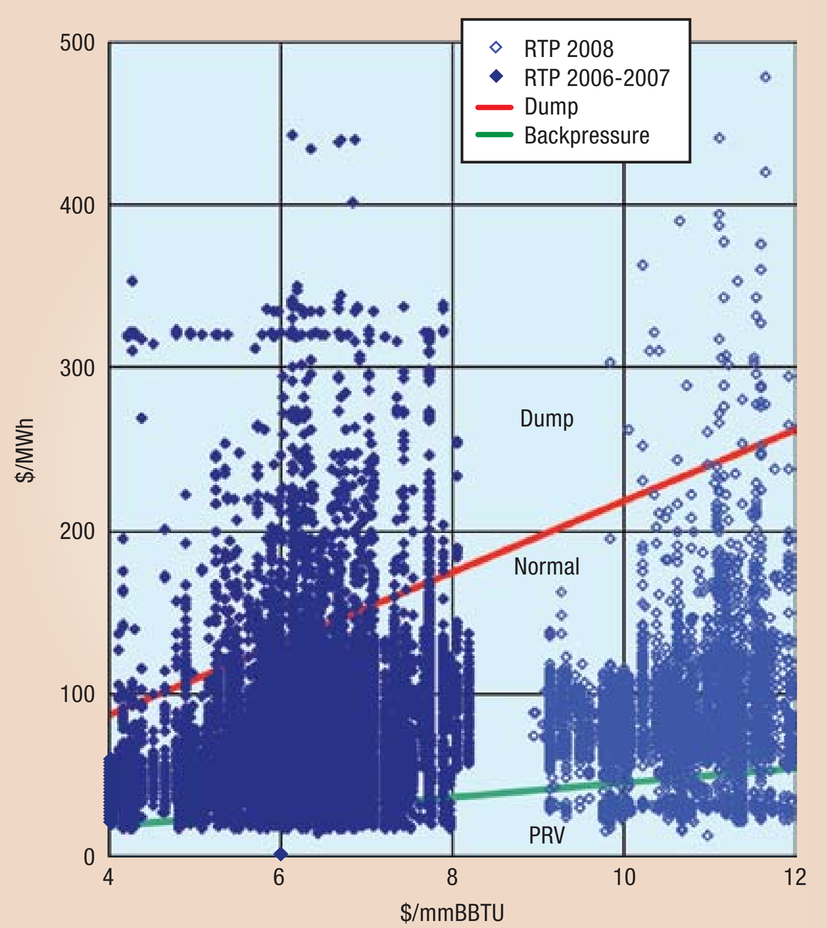
The Point Comfort powerhouse is a large facility with multiple boilers, turbines and steam headers. Operating the plant is a major challenge, due to fluctuating energy prices, plant complexity and high reliability requirements for steam and power supplies. To improve operational stability and flexibility while reducing energy costs, a new application was installed for coordinated control and optimization.

At the top level, an optimization program monitors the current plant situation and gathers energy pricing data over the Internet to make timely decisions about loading individual powerhouse equipment. The optimization program then dispatches these orders to an advanced control layer, which executes the optimizer's plan in a closed-loop fashion. The upper decision support layer is implemented using linear programming with mixed integer (LP/MIP) capability for economic optimization. The advanced control layer uses a model predictive controller (MPC) providing coordinated, decoupled control of header pressures and megawatts. The optimization system was commissioned in 2005 and has been an integral part of the operations ever since the initial start-up.

Highly Variable Energy Costs

Optimizing the Point Comfort power plant operation is complicated by the changing markets for fuel and electricity. The highest price of electricity in any given day may be more than 30 times that of the lowest. Gas price variations are more gradual, but significant over a longer time period. The variation of fuel and power prices drives the selection of the power plant operating mode. When the purchased

Figure 2 ELECTRICAL POWER VS. FUEL COST



power price is high as compared to the natural gas cost, more power should be generated in-house, and vice versa.

At Point Comfort, most of the energy needed by the process is generated at the facility's power plant, including 1.2 million pounds of steam an hour and 55 MW of power. Approximately 20 MW of supplemental electricity is purchased from the grid. The powerhouse produces high-pressure steam and delivers low-pressure steam to the process at various pressures and temperatures, co-generating electricity as a byproduct. There are six high-pressure boilers, two low-pressure boilers, four double-automatic extraction-backpressure turbines, steam vent valves and pressure reducing valves (PRV) with desuperheaters. (Figure 1.)

The power plant has a distributed digital control system (DCS) for process control that was installed during the past 20 years. The system expanded to include all the boilers, turbines, PRVs and vent valves. The turbines were retrofitted with modern fast-acting hydraulic actuators connected to the DCS.

The control logic used before the optimization project was based on boiler-following strategy, typical for industrial cogeneration plants. In this scheme, the low-pressure steam headers are controlled by the turbines and all the variations in steam demand end up in the turbine throttle flows and the high-pressure steam header. A common "plant master" system raises and lowers fuel flows of all high pressure boilers together to maintain the header pressure at setpoint. The low-pressure boilers have separate controllers for the boiler pressure and steam flow control. The PRVs are opened when the turbine extractions cannot maintain header pressures above their minimum settings, and the vent valves only act when the header pressures become high.

As all these control loops at the base control level acted independently, it is difficult to optimize the process and frequent operator intervention is required. During large process upsets it is difficult to maintain the steam conditions of the various headers within acceptable limits.

High Reliability Requirements

The alumina refining process is complex and sensitive to energy supply disruptions. Disturbances causing boiler trips are particularly problematic, since a single boiler trip could have a cascading effect taking other boilers down. Improving power plant stability was one of the key operational objectives of the optimization project.

Because of the manufacturing process' large steam demand, a large portion of power at Point Comfort can be generated as backpressure power. This is the most efficient form of power generation, as the steam exiting the turbines is used for process heating. Because of the high overall efficiency of backpressure power, the lowest cost operation is usually achieved by maximizing it. At Alcoa, this is called the "normal mode" of operation. When in "normal" mode it is important to maximize the use of high-pressure boilers before using the low-pressure boilers, as the steam from the high-pressure boilers expands longer in the steam turbines, generating more backpressure power from the same steam flow.

When the purchased power price is high, internal power output can be increased by venting steam. This increases steam flow through the turbines and more power is generated. At Alcoa this is called the "dump mode." Due to the large heat losses, the cost of the additional power from dumping is high, but can still be less than the cost of purchased power it replaces.

At times, the purchased power price can be low, even below the cost of backpressure power. It is advantageous then to bypass the turbines by opening the pressure reducing valves (PRVs). As steam exits the PRVs at a much higher temperature than can be accepted by the steam users, water is sprayed into it in desuperheaters to cool the steam. This water generates additional steam and therefore less steam needs to be generated by the boilers, providing savings in fuel costs. When pressure- reducing valves are opened to reduce fuel consumption, it's called the "PRV mode" at Alcoa.

The optimum selection between "normal," "dump" and "PRV" modes depends on the gas and power prices. (Figure 2.) Both the backpressure power cost (green line) and the dump power cost (red line) are directly proportional to the gas price. The purchased power price is most often between the backpressure and dump power costs, resulting in the selection of "normal" mode.

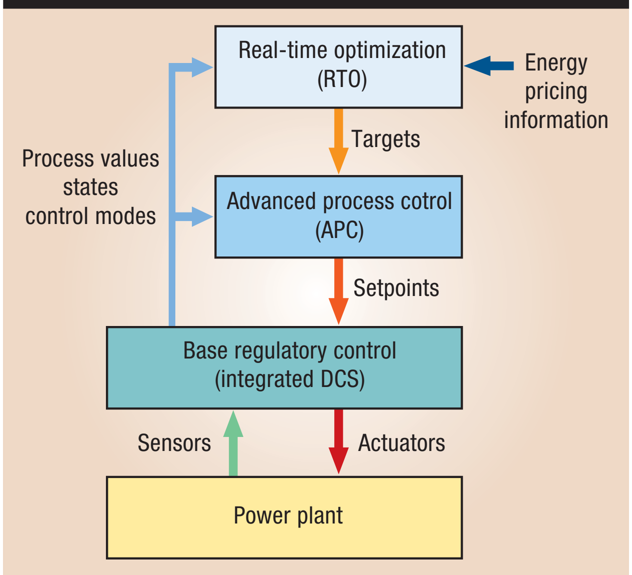
Multi-level Optimization

Power prices change every 15 minutes and natural gas prices change on a daily basis, so the powerhouse operating mode must be changed frequently. To further complicate the situation, each mode change creates a large disturbance to the power plant. For example, a fast move from "normal" to "dump" causes a large increase in steam demand that the turbines and the boilers must respond to. Therefore, keeping the plant at the optimum is a major challenge.

To enhance the powerhouse stability and to realize optimum operations, the Alcoa Point Comfort staff examined several software programs for online application. A multi-level approach (Figure 3) was selected that uses real-time optimization (RTO), connected to advanced process control (APC). At the top level, an optimization program monitors the current situation in the plant and gathers pricing data over the Internet to make timely decisions about loading individual equipment in the plant. The optimization program then dispatches these orders to an advanced control layer, which provides coordinated, decoupled control of pressure and power generation. The base control level modulates the actuators affecting the plant to maintain the measured process quantities at their setpoints.

The optimization layer uses linear programming technology (LP). LPs are common optimization tools used for planning and scheduling applications in many industries. The LP minimizes an objective function (cost of fuel plus cost of purchased electricity), while adhering to many constraints. Some of the constraints are part of the plant model, representing mass and energy balances. Other constraints represent capacity limits, such as maximum fuel flow rates to boilers, generator, etc.

Figure 3 MULTI-LEVEL OPTIMIZATION SOLUTION



The LP makes the selection between the operating modes (normal, dump and PRV) based on the fuel and power pricing situation and the plant conditions. The selection cannot be made on pricing information alone. The equipment limits are higher priority and they must be honored for safety and equipment protection. The constraint set continually updates, as process conditions drift and available equipment varies with maintenance schedules.

The advanced control system uses technology known as model predictive control (MPC). MPC is a multivariable control algorithm. Like the LP, MPC uses a model, but it's dynamic rather than steady-state. MPC runs at a much higher frequency than the LP, less than 10 seconds compared to 15 minutes. Using the model, the controller predicts the effects of moving multiple base control setpoints on the system pressures. MPC is moving high pressure and low pressure boiler fuel setpoints, all three extraction valves on all four turbines, all PRVs and all vent valves (a total of 28 manipulated base control setpoints).

The algorithm is capable of providing smooth transitions, whether opening PRVs, closing vent valves or controlling the steam balance with LP boilers when the HP boilers are maximized. In case of large process upsets, the MPC uses all steam system components to help out, allowing temporary deviations from their optimum targets. As the MPC is a multi-variable algorithm, all the required operating modes are achieved with a single MPC configuration. The overall design is greatly simplified as there is no need for alternative DCS configurations or complex over-ride schemes at the base control layer for boiler-follow, turbine-follow, PRV and other such modes.

The most immediate benefit from the implementation of the new strategy was the greatly improved process stability. Main steam pressure standard deviation was reduced by 80 percent, and similar improvement was observed in all other headers. Improved pressure control is important, since the optimization requires the powerhouse equipment to make more frequent transitions between maximum power generation and minimum fuel operating modes. The better control of the steam headers has also eliminated situations where a single boiler trip causes others to trip, reducing plant outages and production losses.

Economic targets for the optimization system were also achieved immediately after implementation. Verified savings of 1 percent in the powerhouse overall energy costs were realized, providing a payback time of six months for the advanced control and optimization system. Initially, 70 percent of the savings came from the maximization of backpressure power, 15 percent by using the most efficient boilers, 10 percent from buying the maximum power when electrical prices were low (PRV mode) and the remaining 5 percent by producing extra power by venting when power prices were high (dump mode). Since the initial start-up of the system, the spread in the power prices has become much larger, increasing the savings from the PRV and dump modes significantly.

Due to the improved stability of operations and better response to upset conditions, the operators have a high level of confidence in the new system and advanced control and optimization has become the preferred mode of operation. The utilization rate of the new system is more than 99 percent for most equipment, in spite of the numerous maintenance and retrofit projects on the boilers and turbines during this time.

One reason for the high degree of operator confidence comes from the belief that cascading plant trips have been eliminated (although this has not be proven.) The MPC controller is able to spread header pressure error over four headers instead of concentrating the error into one header. The control moves are smooth and coordinated. There are fewer phone calls to the process operators requesting manual steam flow reduction, which can cause further disturbances to the power plant. The plant feels the economic benefit of reduced trips is even greater than the significant energy savings costs.

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