

At Daishowa Marubeni, implementation of an energy management system optimizes fuel use and power generation, allowing the pulp mill to achieve extremely low energy costs per ton

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Daishowa Marubeni's Peace River Mill Cuts Costs With Powerhouse Energy Management

Electric utility deregulation and rising fuel costs have made energy cost control a key operating parameter at mills. For the powerhouse at Daishowa Marubeni's kraft pulp mill in Peace River, Alta., implementation of a rule-based energy management system (EMS) has resulted in a minimum reduction in natural gas purchases of 14% and a 13% reduction in total purchased energy. The system also provided a return on investment (ROI) in less than six months. In addition, steam and electric generation quality and reliability improved, and the mill now has one of the lowest costs for energy per air-dried mton of pulp in its class.

The EMS functions to minimize the total cost of energy required by the mill. A PC-based EMS supervisory control system is interfaced to a distributed control system (DCS) to work in tandem with regulatory controls residing in the powerhouse DCS and programmable logic controllers (PLCs). The design is based on fuzzy logic control and employs a new inference engine and defuzzification method. This methodology integrates online optimization and a set of prioritized constraints.

**STEAM AND ELECTRICAL NETWORK.** The powerhouse steam and electrical network is shown in Figure 1.

Black liquor and hog fuels generate more than half of the mill's steam. Most of the process steam is low-pressure steam (1,100 and 400 kPa). High-pressure steam (6,380 kPa) is throttled through the turbine-generator (TG) to generate a significant amount of electrical power. Steam can be throttled by pressure reducing valves (PRVs) or through the condenser or atmospheric vents, but this is minimized as much as possible, since no power is generated.

Process steam and electrical power demand vary significantly at the mill due to changes in batch digester operation, the woodyard, soot-blowers, etc. Sometimes, the power boilers must go from maximum to minimum load and back again within several minutes. This variability makes real time optimization of powerhouse operations challenging.

**ENERGY SYSTEM CONSTRAINTS.** The Peace River powerhouse had to operate within a number of constraints while trying to meet the mill's energy demand at the lowest possible cost. Balancing the optimization function with all those constraints was a difficult task requiring a significant amount of operator intervention. In developing the project requirements, Daishowa determined the need for the following EMS functionality:

1. Minimize power boiler purchased natural gas use while maximizing boiler stability and steam hog fuel, as well as eliminating outside purchased fuels used to control header pressure;
2. Reduce steam venting and excessive steam condensing while maintaining steam header stability, reducing gas use, and avoiding venting while burning natural gas;
3. Maximize electrical power contract production. This would mean increasing power production when import power costs are high, and decreasing power production to ration hog during shortages. Also, the mill needed to generate power in the most cost effective manner by burning natural gas only when import power costs were high and by supporting demand and real time pricing (RTP) rates for optimal generation.

A rule-based system can insert engineering and operational knowledge into a control system for use on a 24 hour/7 day a week basis—all while adhering to constraints. As an operator would, the EMS installed at the Peace River mill sacrifices cost optimization whenever a constraint is reached. The control priorities for the EMS are:

1. Meet all environmental constraints
2. Meet all equipment constraints
3. Meet all process constraints
4. Meet energy requirements at minimum costs

**EMS SUBSYSTEMS.** EMS subsystems include those for boiler load allocation, turbine load allocation, hog-optimization, and pricing control, as well as functions for steam system management. These subsystems can be operated independently. The operator simply selects the subsystem and places it under EMS control.

The EMS control software for the Peace River mill resides in a Windows NT personal computer or can be installed directly in the DCS. It has been designed specifically for implementing fuzzy logic control. There are interfaces to the powerhouse DCS, turbine controllers, and various PLCs.

**Boiler load allocation.** For boiler load allocation, the operator selects which boilers and fuels are to be used. A schematic of the 6,380-kPa header pressure control with the embedded boiler cost optimizer is shown in Figure 2.

The powerhouse master controller incorporates a fuzzy matrix controller that offers advantages over a proportional integral derivative (PID) version. The fuzzy controller executes once per second and sends a request to the boiler cost optimizer for an incremental steam change.

The boiler load optimizer integrates three distinct functions that must be balanced. One function represents a safe operating envelope with prioritized environmental, equipment, and process constraints. An optimization function adjusts multiple boilers and fuels to obtain the most economical operating solution. And, finally, header pressure control stability is addressed so power boilers with widely varying response capabilities can work together.

The boiler load allocator observes all predefined constraints before adjusting boiler fuel flows to create a safe operating envelope, prevent boiler damage, and avoid undesirable operating regions. Typical constraints for a boiler are (in order of priority):

1. Maintain opacity (six-minute average) below maximum;
2. Keep induced draft (ID) fan speed within control range;
3. Prevent furnace draft from going positive;
4. Maintain drum level in safe range;
5. Prevent excess oxygen from going too low;
6. Keep boiler steam generation within limits.

The allocation function is embedded in the header pressure control loop. Continuous disturbances to header pressure caused by variations in steam demand means boiler load allocation also takes place on a continuous basis. Direct application of steady state optimization methods does not work for a process that is never at steady state. Instead, a dynamic boiler allocation method is used. In this solution, the optimization method has been converted to an optimization rule set that is integrated into the overall rule set.

An incremental steam generation cost (\$/mton of steam) is continuously calculated for each fuel based on the fuel cost (\$/gigajoule (GJ)), the selected "swing" fuel, and incremental boiler efficiency for the selected fuel. This efficiency number is entered based on historical data or online calculations. For incremental steam increase requests, boilers and fuels with lower incremental steam costs are favored more than boilers and fuels with higher costs. For incremental steam decrease requests, boilers and fuels with higher incremental steam costs are favored. In the short term, if more expensive steam is required for good header pressure control, it is used.

**Hog fuel optimization.** Hog fuel optimization is incorporated in the boiler load allocation function. The operator enters a minimum and maximum hog fuel rate limit, but the desire is to maximize the hog rate as much as possible. In a multi-fuel boiler, each fuel is treated as if it were a separate boiler by the allocator. The cost of hog (\$/GJ) is entered as a very low value.

Transport time delays prevent hog fuel from being an "effective" swing fuel. However, an operator adjustable "aggressiveness" factor is used to allow hog to be treated as a pseudo "swing" fuel and maintain stable header pressure control.

Normally, hog flow will remain at the maximum limit (entered by the operator) and header pressure control is accomplished by adjusting gas flows. However, there are periods of low steam demand when hog flow must be reduced to prevent excess venting of steam to the atmosphere. When the fossil fuel is at minimum limits and further steam generation reduction is needed, the boiler allocator will reduce the hog flows of the power boiler. When the process demand increases, hog starts to increase. Hog is considered "somewhat" base loaded, since it always works its way back to the maximum limit.

**Steam system management.** The EMS also addresses proper steam allocation to satisfy steam header and electrical generation requirements. Improved steam system management reduced steam losses 16% (vent and condenser) for hardwood pulp and 36% for softwood while maximizing the electric generation requirements and improving steam header reliability. The system components controlled by the EMS to effectively manage the steam system are the header pressure and turbine load.

One of the major challenges of implementing boiler load allocation control is maintaining stable header pressure control for all combinations of boilers, fuels, and equipment conditions. Multi-fuel boilers using hog burned on a traveling grate pose problems because of wet hog fuel, long lag times, and "piling" on the grates.

An initial "aggressiveness" factor is assigned to each boiler fuel, and this factor can be adjusted to compensate for fuel variations specific to the location. This determines the degree to which it participates in header pressure control. The factor and, therefore, use can vary from no participation to full use or any value in between.

Matching the "aggressiveness" factor to the responsiveness of each boiler is important for achieving stable header pressure control. Reducing the participation of boiler fuels that have poor steaming response is also essential. However, there must be at least one boiler fuel (in large plants, preferably two) that has a fast steam response if satisfactory header pressure control is to be obtained.

Sometimes, boiler constraints reduce header pressure control effectiveness. As a boiler approaches a limit, its participation in header pressure control is reduced to zero. When some limits are exceeded, such as boiler steam generation, constraint controllers may make counter control moves to place the boiler back inside the safe operating envelope.

**Turbine load allocation.** The EMS's turbine load allocation subsystem provides supervisory control for the TG extraction flows to minimize PRV flows and maximize the total power generated. The TG is assigned primary responsibility for control of header pressure and purchased power.

**Real time pricing (RTP) tie-line control** adjusts the load to the condenser via the TG and throttling valves. The turbine load allocator adjusts the 1,100 kPa and 400 kPa flow set points in the TG controller to achieve turbine load allocation. Both flow set points continue to be "bumped up" until a constraint is reached.

**RTP TIE-LINE CONTROL.** Most industrial customers purchase power on a 15 or 30 minute interval with a demand component and fixed energy charges for on and off-peak periods. Real time pricing is a new schedule available from many electric utilities where tomorrow's hourly prices are provided based on the grid load and generating capability. There is no demand charge or demand interval. Instead, the price of electricity varies on an hourly basis. Customers can purchase all the power they need without worrying about setting a new peak demand. However, prices can be high. For example, they exceeded \$1,000/MWh during peak daytime summer periods at the Peace River mill.

The ability to select the most attractive electric rate schedule is a critical function of the EMS's RTP tie-line control subsystem. Tie-line control for the EMS has three modes: RTP, Demand MW, and Constant Purchase MW. However, the RTP mode is becoming more important, since some utilities will provide attractive economic incentives for excess power generation or demand side management during peak periods. The objective is to reduce the mill electric demand or, at some mills, generate power onto the grid when utility demand is high. The primary control objective for the Peace River mill is to adjust the TG's steam flow to the condenser or vent to minimize the cost of providing the mill electrical deficit, while still staying within a predefined safe operating envelope.

**Mill electrical deficit.** To implement an RTP or demand tie-line controller, the mill electrical deficit had to be controlled. The electrical deficit is defined as total electrical power demand minus the power being generated by the turbine. There are three sources of power that can be used: purchased power, forced condensing power, and venting (400 kPa steam) power. The RTP control algorithm uses the mill electrical deficit to select the proper operating mode and to minimize utility costs.

**RTP control algorithm.** A schematic of the RTP tie-line control algorithm is shown in Figure 3.

The prioritized constraints shown in the top part define the safe operating envelope. This turbine is "herded" to stay within the envelope while the tie-line control function is performed.

Electrical prices are automatically downloaded to a buffer each night and the incremental cost to generate the next MWh by forced condensing is continuously calculated. When it is less expensive to buy power, the control algorithm decreases turbine condensing until it encounters a process constraint. When it is less expensive to make power, the algorithm increases condensing until it encounters a process constraint. If costs are nearly the same, condensing is controlled to mid-range of the loads on the power boilers for maximum operating flexibility. The control algorithm adjusts the turbine's load to minimize electrical costs only when all variables are within the safe operating envelope. Ultimately, the control sacrifices minimum cost for safe process performance.

**EMS BENEFITS.** The Peace River mill saw an accelerated return on investment with the EMS project. The ROI, which was initially estimated at one year, was achieved in less than six months.

The Peace River powerhouse operates to minimize purchased fuel use and maximize waste fuel use in order to reduce energy cost and emissions. Table 1 shows that the EMS system resulted in a reduction in outside purchased energy costs of 13% when running softwood and 21% on hardwood. The EMS has been in continual automatic operation since 1999 and several specific benefits have been identified:

- Steam users at the Peace River mill report more stable header pressure, which provides smoother operation of the pulp dryers through consistent dry air availability. Stable header pressure also means more stable evaporator operation;
- The mill has seen greater power boiler operating stability, meaning operations can run with reduced or even no natural gas. Also, a higher percentage of steam from hog fuel is used. All of these improvements add up to considerable cost savings;
- Lower venting/dump to condenser flows was also reported with the EMS, reducing natural gas usage, power boiler steam production, and overall steam production. These reductions brought further cost savings, as well as reduced stack emissions;
- More stable operations within the powerhouse allowed the EMS indicator to identify bottlenecks, since units ran consistently on the edge of optimal performance.

TABLE 1. The EMS reduced Peace River's gas use and steam generation on both hardwood and softwood pulps.

Combustion Data	Hardwood			Softwood			Units
	Before	After	Delta	Before	After	Delta	
<b>Total steam production</b>							
power & recovery	7.171	6.897	-3.82 %	9.439	8.997	-4.68 %	T/ADMT
Power boiler gas	2.654	1.756	-33.84 %	2.412	1.392	-44.29 %	GJ/ADM T
Power boiler steam							% Steam
from hog fuel	74.70 %	83.20 %	11.38 %	80.20 %	86.50 %	7.86 %	from hog
Power boiler steam	2.437	2.332	-4.72 %	2.823	2.446	-13.35 %	T/ADMT
Total gas purchase	4.661	3.623	-22.27 %	4.498	3.87	-13.96 %	GJ/ADM T
Total purchase energy	4.715	3.706	-21.40 %	4.487	3.897	-13.15 %	GJ/ADM T

P&P

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FIGURE 1. The powerhouse uses several fuels to generate steam and supply the mill's turbine generator.

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FIGURE 2. The header pressure control system with an embedded boiler cost optimizer balances cost minimization while maintaining a safe operating environment.

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FIGURE 3. Real-time pricing control adjusts turbine operation to operate within prioritized constraints while the tie-line control function is performed.