Improving industrial powerhouse operations with an energy management system

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ABSTRACT

Industrial powerhouses use distributed control systems (DCS) to increase operational efficiency. The DCS provides regulatory control and increases the flow of information. Efficiency can be increased—along with greater cost savings—by installing an adjunct energy management system (EMS) with the following functions:

- *Header pressure stabilization*
- *Supervisory control of electrical tie line with real-time pricing*
- *Economic model for calculating best-operating-cost recommendations*
- *"What if" capabilities*
- *Load shedding*
- *A well-designed user interface.*

The main challenge in developing EMS programs is the complexity of accommodating such a wide array of functionality within a single system. Conventional programming methods are cumbersome and often produce results that are less than satisfactory. This paper describes an EMS prototype application that provides a configurable solution for increasing powerhouse efficiency. The proposed system provides a new set of rule-based, model-based, and numerical optimization tools, an advanced operator interface, and ready access to information in the DCS.

Application:

Describes a supervisory energy management system that can reduce operating costs for industrial powerhouses.

STEAM AND ELECTRIC POWER ARE among the basic raw materials of the pulp and paper industry. The U.S. pulp and paper industry is the nation's fourth largest consumer of energy and the third largest in energy purchases.* The industry is also the nation's leading cogenerator of electric power. Clearly, even small improvements in the operating efficiency of pulp and paper powerhouses will provide significant financial benefits.

Operating efficiency can be improved by using an energy management system (EMS) that supports the following six functions:

1. Header pressure stabilization to improve the efficiency of process steam users by treating the steam supply chain from producers to consumers as an integrated system that must be operated in the most efficient and economical manner.
2. Supervisory electrical tie-line control with real-time pricing to control power purchases during a given time interval, thus ensuring that the nominated purchased power is cost-optimally consumed but not exceeded. This also includes determining the amount of power to be nominated from production forecasts and resource availability, and accommodating table-based or real-time pricing by the utility.
3. Best operating-cost calculations and recommendations (economic model) to cut costs. The model can calculate, on a near-real-time basis, the cost of energy production and a best-cost operating scenario within the limits of the operating protocols. With this information, management can evaluate make-or-buy decisions on electrical power and align steam production accordingly.
4. "What if" capabilities to determine the economic impact of alternative scenarios. The economic model is used to assess the relative costs of different control strategies.
5. Load shedding to notify operators when conditions require power load shedding. The system can initiate load shedding based on conditions in the mill and manage defined load-shed protocols.
6. Well-designed user interface to promote effective use of the system. Desirable features include object-oriented, icon-based screens for ease of use and navigation, fully configurable graphic presentation of information, in-context advisory information, in-context presentation of diagnostic and troubleshooting information, and a fully configurable graphic capability to define the system's functionality.

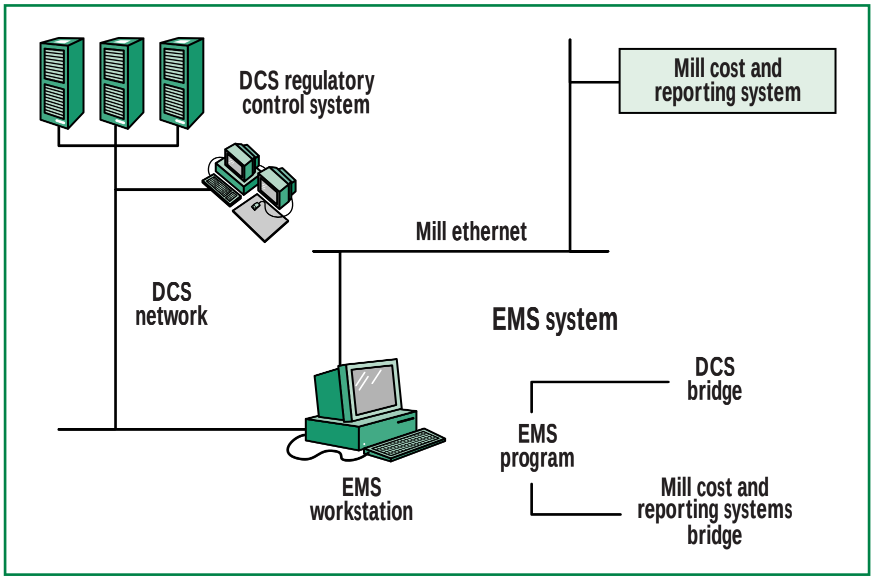
This paper describes an EMS prototype application (expertEnergy™) developed by Simons Engineering that uses Intelligent Systems technologies (G2 by Gensym Corp. and MESA by The MESA Co.) to provide a configurable solution that addresses the complex problem of improving powerhouse operations.

SYSTEM OVERVIEW

The EMS is designed to interact with an effective regulatory distributed control system (DCS). The DCS provides:

- Control of the fuel, feedwater, drum level, steam pressure, and air flow of the boilers based on demand for steam and the firing protocols.

* *Steam—Its Generation and Use* (S.C. Stultz and J.B. Kitto, Eds.), 40th edn., Babcock & Wilcox, Baberton, OH, 1992, p. 26-1.



1. Simplified EMS architecture

- Primary control of steam turbines based on the turbine control logic such as exhaust pressure control.
- Control of steam header pressure by (a) adjusting turbine extraction and boiler firing rates as the primary strategy and (b) opening pressure-reducing valves (PRVs) as a secondary strategy.
- Operator interface for these controls, including alarming and status of auxiliary equipment.

The EMS provides supervisory monitoring and control for the regulatory DCS. The EMS typically provides a summary of operating information (demand, usage, and cost) to other mill applications (reporting and accounting systems). The EMS also requires cost information (fuel price, etc.) to calculate the operating expenses that inform the decision-making process.

The EMS resides on a dedicated computer workstation that is connected to the regulatory control system through the DCS network. The connection is made through standard bridge software that supports bidirectional communication of information between the two systems. Through this connection, the EMS can provide both heuristics (rule)-based and model-based approaches to support the required functionality. A connection to other mill systems (cost and reporting) is made over Ethernet using bridge software. Figure 1 is a simplified diagram of the system architecture.

EMS FUNCTIONALITY

EMS functionality is provided by a custom-developed configurable energy-management application. The proprietary technology used as the basis for this application provides a number of advantages in dealing with the EMS complexity. These advantages are described in the following discussion of system functions.

Header pressure stabilization

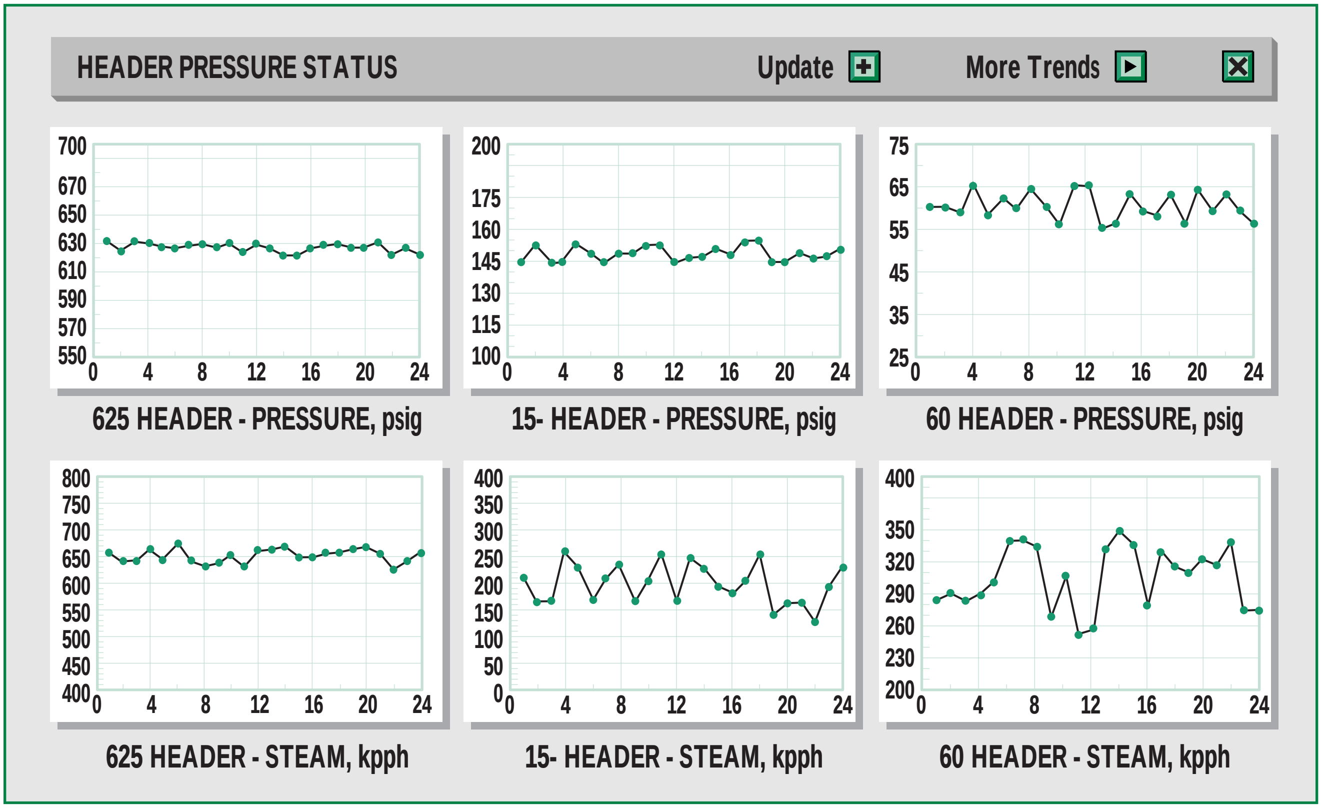
Stabilization of steam header pressure at the most economical cost is a key EMS function. Header pressure stabilization is an interaction between boilers, turbines, and PRVs. A conventional DCS responds to falling pressure by adjusting turbine extraction flows in relation to condenser exhaust or, if the process demand cannot be met, PRVs are opened to provide additional steam. Boiler firing rates and condenser flow are adjusted accordingly. The opposite actions are taken on high header pressures.

This strategy often leads to swings in header pressure because of the mass and inertia of the system and the decoupled nature of the control actions. Such swings can result in operational problems with producers (boilers) and consumers (process equipment). Swings are inherently costly because electrical generation capacity is reduced, thus increasing consumption of purchased power, with the associated usage and demand charges.

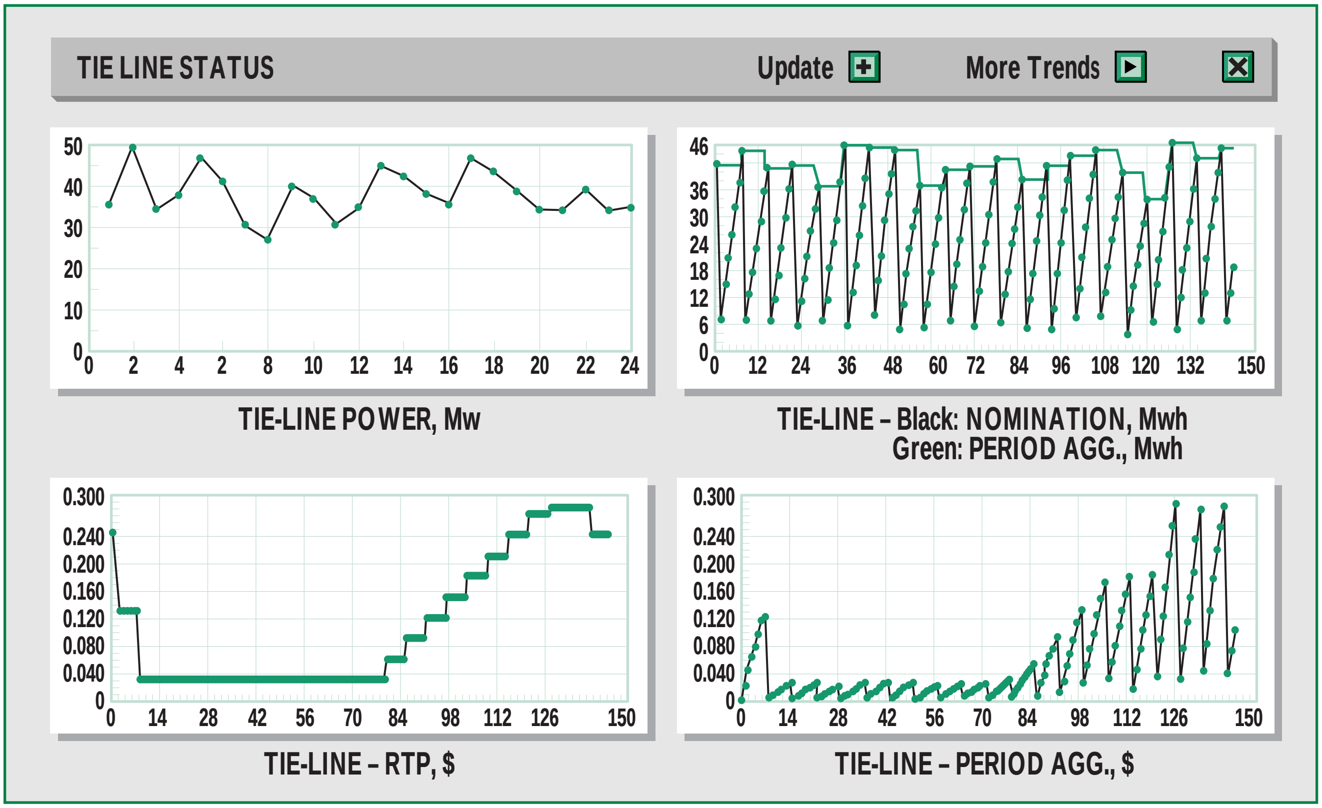
The EMS approaches the problem of header pressure stabilization by treating the entire steam supply chain from producers through converters to consumers as an integrated system. This approach operates under the assumption that the conditions and actions at any part of the system affect all other parts.

The EMS strategy begins with the end of the supply chain—the users. Steam flow to major users is monitored to predict when steam demand will change. If available, production schedules can also be used to predict large changes in steam demand following startups and shutdowns. For major pieces of equipment, a steam demand curve could be used to more closely predict usage over time (warmup, startup, running, shutdown). This flow of information is used to adjust (with the appropriate lags) supplier (boiler) firing rates while biasing converter (turbines and PRVs) setpoints.

Using data from the EMS function for best operating cost, the most cost-effective boilers and turbine generators (considering both extraction rates and condensing power) for a given steam demand can be calculated and implemented. This usually means adjusting (at efficient producer settings) boiler firing rates to ensure that adequate process steam is delivered (consumers are satisfied) and turbine extraction is maximized (subject to turbine capacity and process demand) while the amount of steam letdown by the PRVs is



2. Header-pressure status screen



3. Tie-line status screen

STEAM SUMMARY   Update   Fuel Advisory   Trends

	Efficiency	Fuel			Steam	
Equip	(%)	(Type)	(LB/HR)	($/Unit)	(PPH)	($/MMB...
"PB1"	68.6	"Stoker Coal"	0	0.032	370000	3.1
		"TRS Gas"	0	0		
		"Bark"	1.44e5	0.009		
		"No. 6 Fuel Oil"	1558.569	0.08		
		"unknown"	0	0.0		
"PB2"	82.8	"Stoker Coal"	32170.0	0.032	340000	3.04
		"TRS Gas"	0	0		
		"Bark"	0	0.009		
		"unknown"	0	0.0		
		"unknown"	0	0.0		
"RB1"	0	"Black Liquor"	59760.0	0	185000	0
		"unknown"	0	0		
		"unknown"	0	0.0		
		"unknown"	0	0.0		
		"unknown"	0	0.0		

4. Economic data example

minimized (the highest conversion efficiency is maintained). The EMS can use rule-based and model-based technologies to implement these functions effectively. Figure 2 shows an EMS screen for monitoring header pressure status.

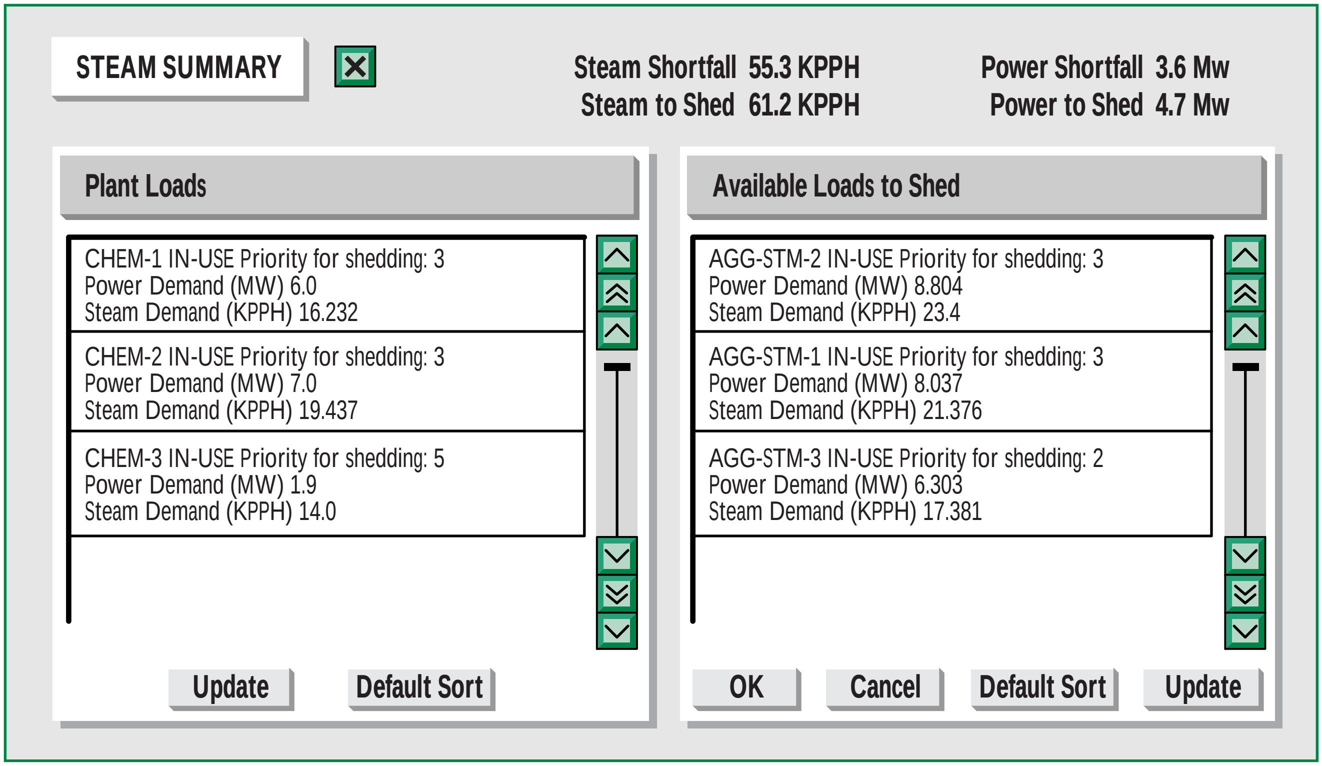
Supervisory tie-line control

Purchased power contracts are normally based on two charges: a usage charge for actual power used over the billing period (typically a month) and a demand charge for the highest usage recorded over a given rolling time interval (usually 30 or 60 minutes) called the demand interval. The demand amount for an interval is nominated by the mill over the life of a purchased power contract (often a year or more). The penalties for exceeding the nominated demand are severe, and once a new demand peak is set, the demand charges are often increased for the life of the contract. The demand charge can exceed the usage charge. Complicating the economical purchase of power is the time-of-day pricing, where the demand charges vary over a 24-hour period. (Note: time-of-day pricing and future power-wheeling opportunities in a deregulated market require EMS access to on-line utility bulletin boards and internet-based OASIS sites.)

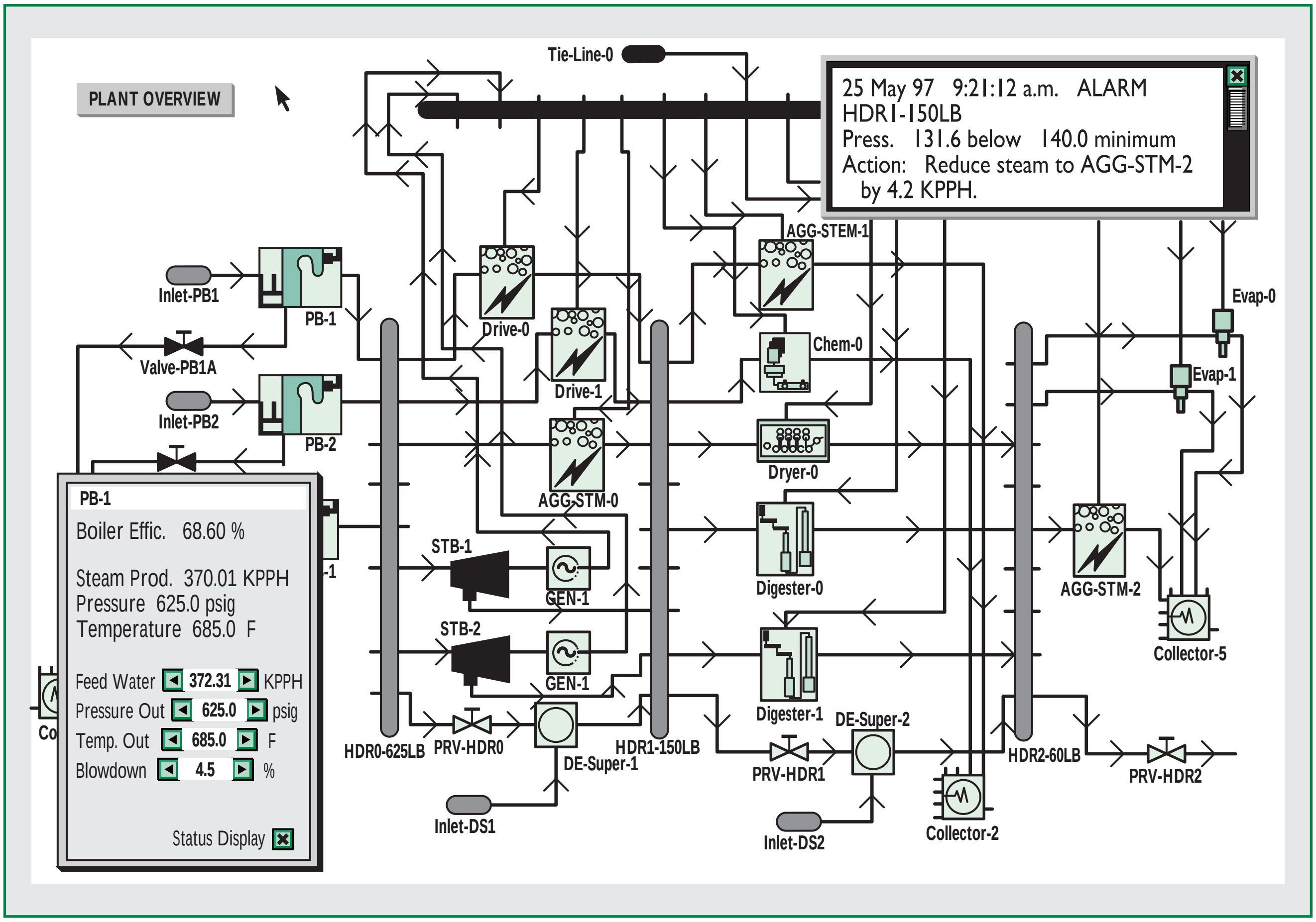
Tie-line control is the ability to control the amount of power purchased from the utility over the demand interval. The most economical operating point for the mill is typically a power purchase that approaches but does not exceed the nominated amount for the demand interval. There are many factors to consider in tie-line control, and because it is so critical, a base level of tie-line control should be implemented in the DCS.

Tie-line control consists of monitoring power usage at one-minute intervals and calculating rolling demand. This is added to the demand predicted for the remainder of the demand interval. If the calculated demand plus the predicted demand exceed the total nominated demand, then the amount of power purchased must be reduced below the amount nominated to avoid severe demand charges. Reducing purchased power involves increasing the amount of mill-generated power and potentially reducing the amount of power consumed.

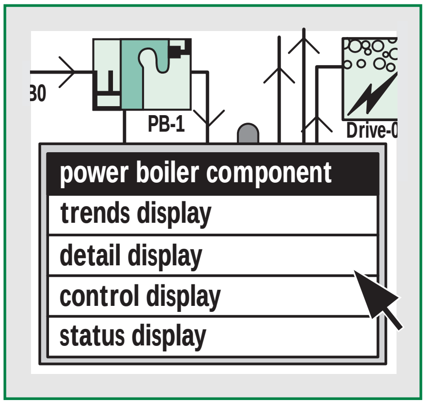
The EMS strategy is to predict what actions will meet the purchased-power reduction requirement and make the appropriate adjustments based on that prediction. It begins with a look at the converters—the turbine generators—to determine if additional power can be generated. If possible, both turbine output and boiler firing rates (producers) are increased to increase power generation without jeopardizing process-steam consumers. If additional purchased power reductions



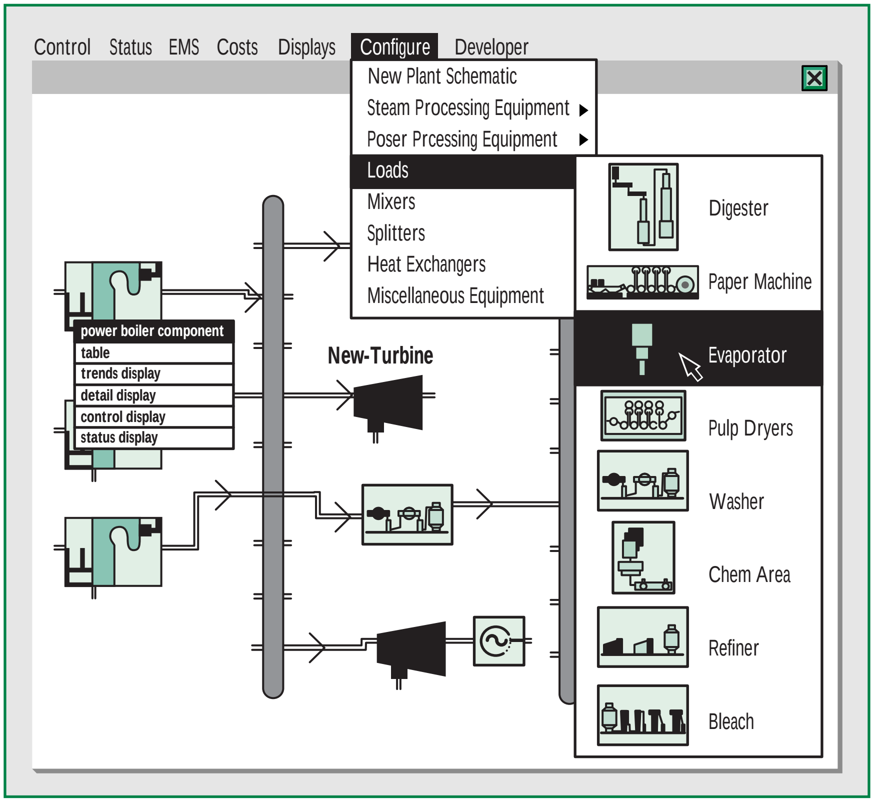
5. Load-shedding configuration screen



6. EMS overview display



7. "Live" icon and table



8. EMS model configuration screen

are needed, then power consumers must be throttled back or shed to reduce power used and/or nonessential steam consumers must be throttled back to provide additional steam for the turbine to generate condensing power. All predictions are made considering the mill's operating protocols and the EMS function for best operating cost. Once the best strategy is predicted, the supervisory tie-line function adjusts the appropriate setpoint and bias points in the DCS to achieve the desired results. Figure 3 shows an EMS screen for monitoring tie-line status. Note the upper right-hand graph showing the power demand for each period just equaling the nominated amount.

The EMS typically uses a model-based strategy for prediction during relatively steady-state conditions. It uses a rule-based approach during transient conditions and for implementing the operating strategy functions of supervisory tie-line control.

Best operating-cost calculations and recommendations (economic model)

To achieve the optimum balance of production output and production costs (best operating cost), the EMS must be able to calculate, on a near-real-time basis, the cost of energy production and a best-cost operating scenario within the limits of the mill operating protocols. The results of these calculations support make-or-buy decisions on electrical power and establish the criteria for optimizing steam production. They also drive the decisions made by many of the other EMS functions.

Several approaches were considered to support this functionality. These included rule-based, linear-programming, and model-based approaches. A rule-based approach was rejected because of its potential size, complexity, and performance. Linear programming (which is used in a number of energy-management applications) does not support equipment performance curves. A model-based approach was selected for its abilities to predict supplier and converter performance and economics in response to changing mill conditions. Required functions of the model are:

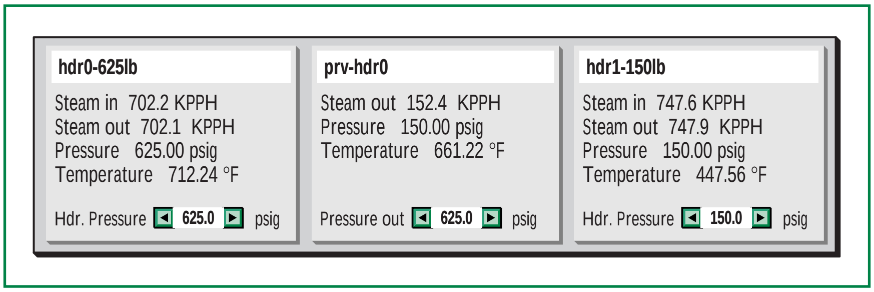
- Accurately simulate the producers, converters, and consumers using mill operating protocols
- Calculate operating costs of the modeled system
- Drive model convergence to best operating costs based on mill operating protocols using an economic optimization algorithm.
- Swiftly calculate the best-operating-cost solution (two to three times per minute) to ensure that regulatory control adjustments, operator advice, and information are provided on a timely basis.

Output from the model is used by four other EMS functions: header pressure stabilization, supervisory tie-line control, "what if," and load-shedding. Figure 4 shows the type of economic data returned to the EMS operator interface.

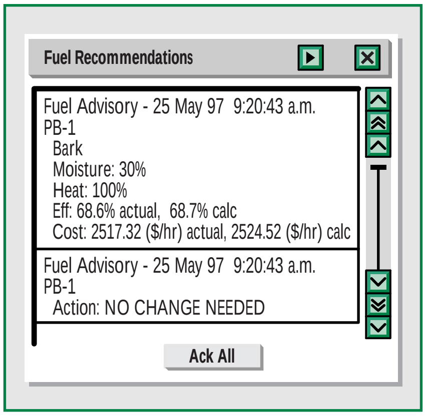
"What if" capabilities

A valuable EMS function is the ability to predict the consequences of taking control and equipment actions that affect the powerhouse and mill operations. These actions include outages of boilers, turbines, or paper machines for maintenance. The ability to manipulate the results of these and other actions through "what if" capabilities allows powerhouse workers to devise the most effective operating strategies to deal with these outages.

The "what if" function uses the other EMS functions, such as the eco-



9. Pop-up steam header faceplate display



10. Fuel recommendations pop-up advisory message board

nomic model, as a basis for predictions and adds an EMS display screen that supports the entry of equipment changes for the various scenarios. Once these are entered, other display screens direct the execution of the scenario and report the results. The reported results reflect the best operating scenario under current operating protocols. They can then be used to plan the outage.

Load shedding

Load shedding is the reduction of power usage in a facility by shutting down or cutting back consumers of electrical power. This is done to avoid setting a new peak power demand, as explained earlier in the discussion of supervisory tie-line control. Load shedding is directly coupled to tie-line control. In many energy management applications outside of pulp and paper, load shedding is a preferred method of tie-line control. In those applications, load shedding is preferred because many of the power loads are nonessential to production, such as building HVAC systems and lighting.

In general, significant electrical loads in a paper mill cannot be shed without causing a production upset. For this reason, load shedding is not a primary function for improving the operating efficiency of pulp and paper mill powerhouses. However, there are times when—for emergency or semiemergency conditions—it is necessary for a powerhouse operator to shed loads quickly. In these situations, the load-shedding function can be very useful.

Load shedding is implemented in the form of pop-up alert/advice windows that inform an operator of the condition that requires load shedding and the action to take. If desired, automatic load shedding could be implemented through EMS-to-DCS supervisory control signals. Either technique requires that the EMS recognize and notify operators of conditions that require load shedding. Load-shedding protocols are based on conditions in the mill and on management-defined load-shed protocols. The EMS uses a rule-based approach to load shedding. Figure 5 shows an example of a load-shedding configuration window. Note that this example shows how both steam and power loads could be selected for shedding.

User interface

A key requirement of an EMS is to provide a user interface that presents information to operators and management in ways that allow them to make good operating decisions on a timely basis. The interface must not only present useful operating information clearly; it must also be easy to learn and navigate. An effective interface must also support system setup and diagnostic capabilities in a flexible and efficient manner. Information should be presented in context, where practical, for ease of assimilation.

A key EMS user interface feature is configurability—the ability to support EMS setup by nonprogrammers. Configurability covers both setup of the EMS application and graphical presentation of information. It allows the base EMS application to be deployed in many powerhouses without large custom programming efforts. It also allows the base EMS application to be changed to support changes in equipment and process by nonprogrammers (within limitations).

Features that should be provided in the EMS interface include:

- *Graphical icon-based displays* that look realistic to users. Figure 6 shows an example of a realistic icon-based display.
- *Information presentation that ranges from overview to fine details*. This should include drill-down capability from menu selections, pop-up dialogs, and "live" equipment icons. Note the pop-up dialog in the upper right and the boiler control display in the lower left of Fig. 6. The boiler control information was displayed by clicking on the "live" boiler icon and selecting "control display" as shown in Fig. 7.
- *Drag-and-drop model construction* using equipment icons that link together with data-passing pipes representing independence and flow of data between icons (objects). This provides a fully configurable, object-oriented graphical representation of the process. Figure 8 shows an example of an EMS model configuration screen with pull-down menu items for drag-and-drop creation and placement of model components. The pipes are created by selecting the stubs on the equipment and dragging to the desired connection point.

KEYWORDS
Computer programs, control systems, costs, efficiency, energy production, management, power plants.

- *Icons representing typical steam and power equipment.* These include generators, converters, consumers, headers, etc. See Figs. 6 and 8 for examples.
- *Attribute configuration of icons* should be used to set up mass, energy-balance, and economic calculations, and dynamics. This is shown on the left side of Fig. 8. Configuration is accomplished by clicking on the icon and selecting "table" to display the setup information.
- *Pop-up displays that group similar equipment* (i.e., boilers, turbines, headers, etc.) with faceplate displays of equipment data (PV, setpoint, etc.). Figure 9 shows an example of steam-header faceplate displays. Note the idealized pressure readings that result from the simulator setup to provide the live data for this paper.
- *Pop-up advisory message board* to log EMS recommendations and inform operators of required actions. The message board should allow operators to acknowledge messages and scroll through a history of EMS recommendations. Figure 10 shows a fuel-recommendations pop-up advisory message board.
- *Tables and charts* that show hourly/daily operating costs for fuels, steam and power, average and incremental costs for steam and power, and total energy costs. Examples of these were shown in Figs. 3 and 4.
- *A "what if" table* to support the setup of gaming scenarios that simulate various operational contingencies.

The operator interface features described in this section make extensive use of the object-oriented nature of the proprietary technology employed.

SUMMARY

Energy costs are a major operating expense in pulp and paper mills. With a good regulatory DCS (distributed control system) in place, a supervisory EMS (energy management system) offers tools to improve operating efficiency and reap the associated cost savings. Such cost savings result from:

- Actions and decisions based on an economic model that provides best-operating-cost decision support within the mill's operating protocols.
- Improved stability in header pressures while operating boilers and turbines at their most efficient points within the mill's operating protocols. This results in more power generated and a more stable steam supply to production equipment. The stable headers also improve the performance of process equipment.
- Supervisory tie-line control that ensures new power demand peaks are not set without a conscious decision on the part of operations management.
- Improved planning for outages and emergency situations using the what-if capability.
- Load-shedding advice for quick and appropriate response to emergency and semiemergency situations.
- An effective operator interface that supports better and more timely operator decision making.

The EMS described here is based on an object-oriented "intelligent system" foundation that greatly facilitates development of the system's predictive and diagnostic tools. **TJ**

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