P^3: Pulp Production Planning

On line planning of Pulp & Paper production

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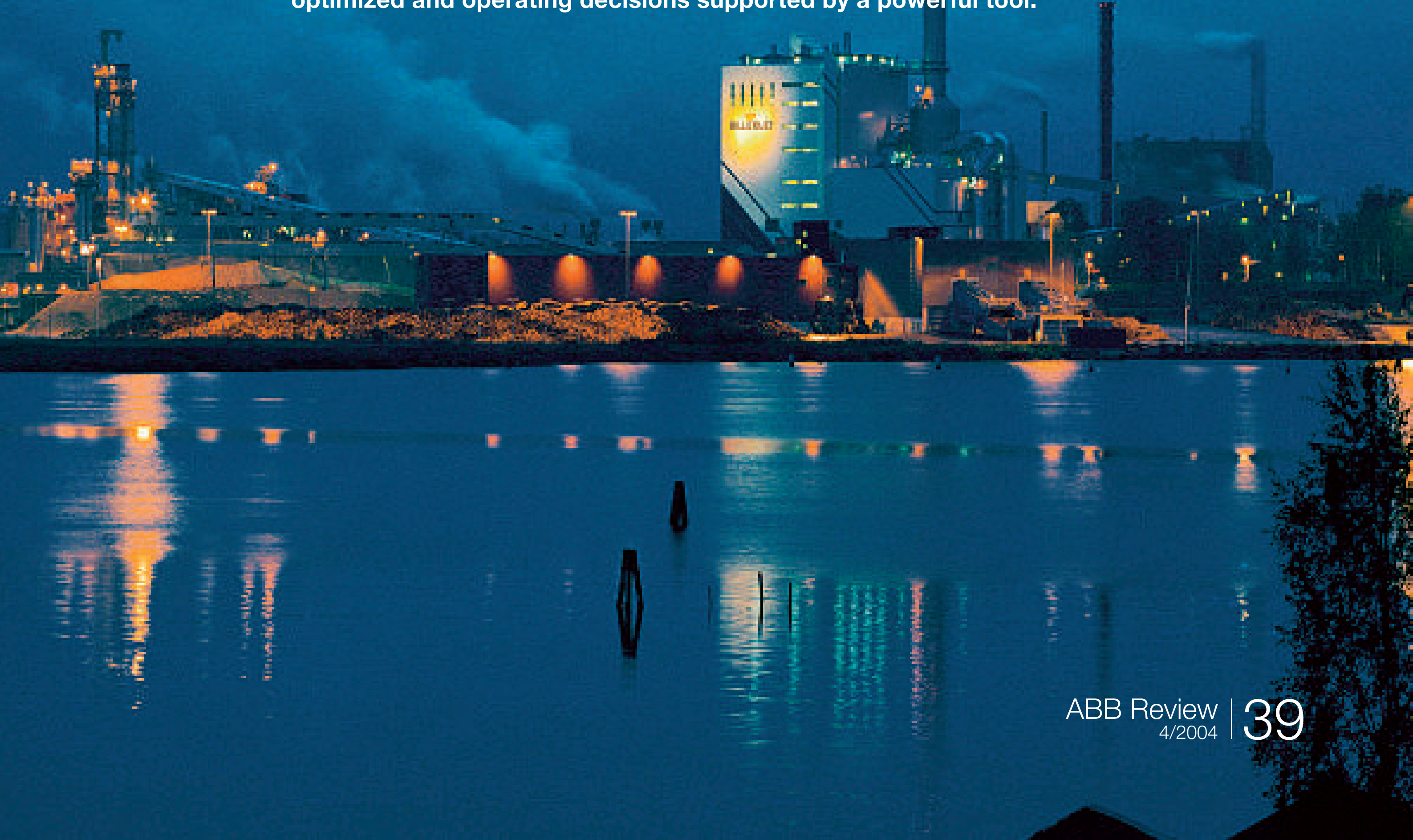
Pulp and paper making is a precise and sophisticated process. To achieve a product of the desired composition, texture and quality, the right mix of chemicals must be applied under the right conditions. Even slight deviations can adversely affect the output.

The plant's advanced control system must maintain the desired quality under normal operating conditions. Additionally, it must react to disturbances. It must also permit individual sub-systems to be throttled to save energy at times when this is expensive and allow them to be closed down for maintenance – all while keeping output as close to the desired level as possible.

ABB's Pulp and Paper online production optimizer helps meet these objectives. Material flows between sub-processes are simulated and forecasts computed from the present state. Mill behavior can be optimized and operating decisions supported by a powerful tool.



Background

Integrated pulp and paper mills are complex systems. The workflow consists of many interdependent sub-process 1. Disturbances at one stage can quickly propagate to other steps and lead to considerable production losses, quality deviations and wastage of material.

It often takes more than 8 hours before the result of a control action has taken full effect in the production process – well into the next crew's shift. Furthermore, the operation and supervision of the different process sections are divided between different control rooms and hence different operators.

Production changes and disturbances directly affect income. It is difficult for operating crews to consider all variables involved in this complex system simultaneously. Predicting the effects of change and taking the necessary actions require appropriate support.

The challenge

The increased recirculation of process streams due to environmental constraints in the pulp mill processes makes the recovery cycle increasingly sensitive to disturbances. These lead to slow oscillations in the chemical composition at different points in the production cycle, in turn causing quality deviations, reduced yield and increasing consumption of chemicals.

Pulp and paper mills consume considerable heat and electric power and hence energy management presents considerable potential for savings. Depending on the location of the production bottleneck, energy costs can be optimized by better use of buffer tank volumes: sections with great heat demand can be operated at reduced load during periods with high electricity prices and buffers refilled when prices are low.

Previous improvement schemes have attempted to minimize losses and quality deviations by identifying ideal operation conditions. The cost of reaching these conditions, however, is not considered. To be truly useful, an optimization must consider processes dynamically. Only in this way can it be used to evaluate remedial actions against disturbances or for operation strategy changes.

Such a tool must optimize mill operations by balancing supply and demand between sub-systems. Every sub-system has to be fed with material, and sufficient supply must be available for the sub-system to produce as required. The system must be as robust as possible towards disturbances or partial closures for maintenance (for example through buffering) and provide a common operating strategy for the whole mill.

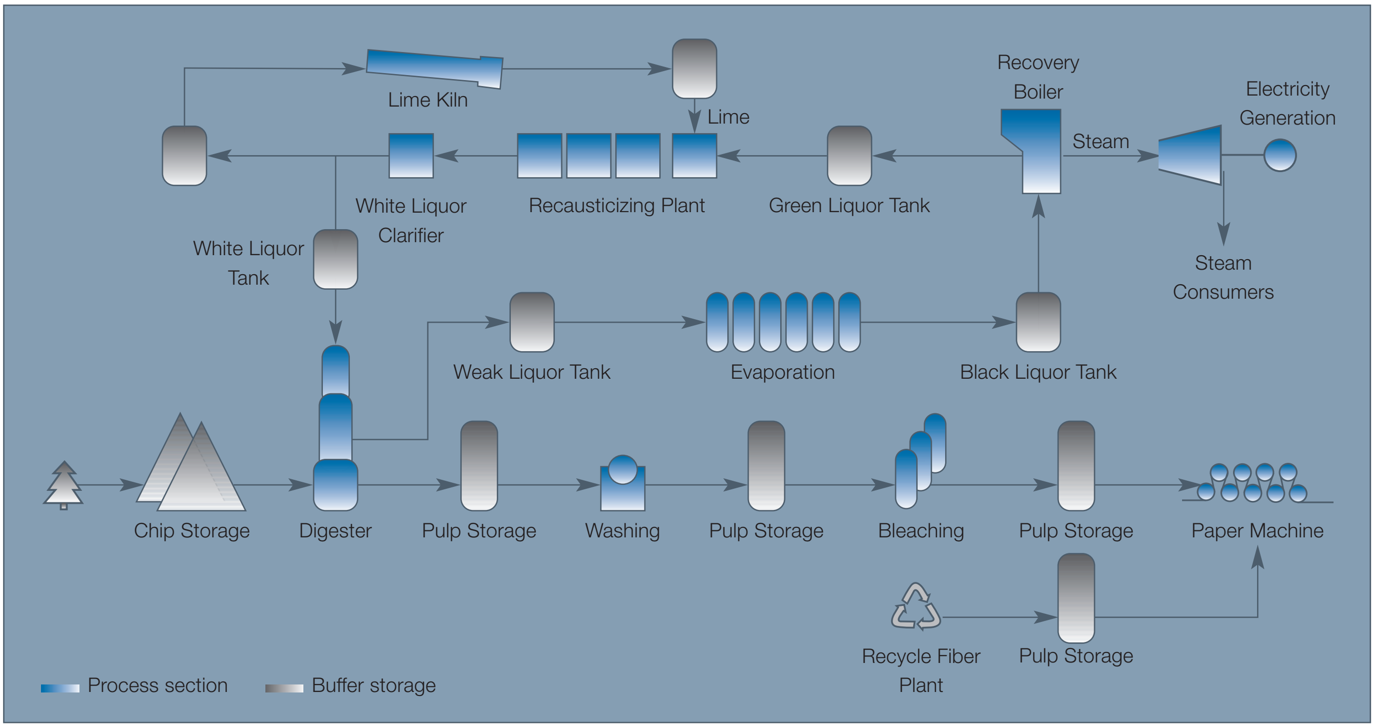
The system minimizes:

- Deviation from the production plan.
- Cost of make-up chemicals.
- Deviation from preferred liquor composition.
- Production loss through disturbances.
- Energy cost.

It supports decision-making in real time through:

- Identification of production bottlenecks.
- Identification of faulty measurements.

1 Generic process diagram of pulp and papermaking process.



- Preparation of the mill for maintenance stops.
- Better decision support for mill management.
- On-line production optimization.

Pilot project

Pulp & Paper On-Line Production Optimizer is an Industrial[IT] application for real time optimization. A pilot installation is in progress at Billerud's Gruvön Mill 2, a large integrated pulp and paper plant in Sweden.

This mill typically produces 640,000 metric tonnes of paper annually. It has six paper machines, three fiber lines and a coating machine. The pulp mill is supervised from five control rooms. It produces sack and kraft paper, containerboard and market pulp.

The mill has recently invested in a new recovery boiler and evaporation plant to raise capacity and eliminate production constraints. To ensure that the anticipated increase in production capacity is achieved, the company is implementing an on-line production optimizer and expects it to boost production and reduce consumption of chemicals to a value of several millions of US dollars annually.

The goals were to minimize the following:

- Variation in active production chemicals composition.
- Cost of make-up chemicals.
- Production losses due to disturbances.
- Variation in amount of active production chemicals in storage.
- Variation of the distribution of active production chemicals in the system.

These goals were met by estimating the state of process variables based on mass balance modeling, and searching for the set of control variables to meet the objectives at minimal operational cost.

Implementation

Modeling – The dynamic mass balance of the complete mill is modeled. The modeling is based on descriptions of all components in the system. These components are categorized into object type groups such as: streams, production units, measurements and calculated properties.

2 Billerud's Gruvön Mill.

Production unit examples are digester, pulp tank, black liquor tank, lime kiln and paper machine. Measurement examples are flow, tank level, sulfidity, effective alkali, reduction efficiency, black liquor density and alkali charge.

Streams are connectors between the process units and described by the total flow and by the concentrations of the different components that are relevant for each stream.

Measurements are connected to either production units or to streams. The pilot mill system with production units, streams and measurements has the following size:

- 25 production units
- 38 buffer tanks
- Approx. 250 streams or pipes
- Approx. 250 measurements or observations
- Approx. 2500 variables

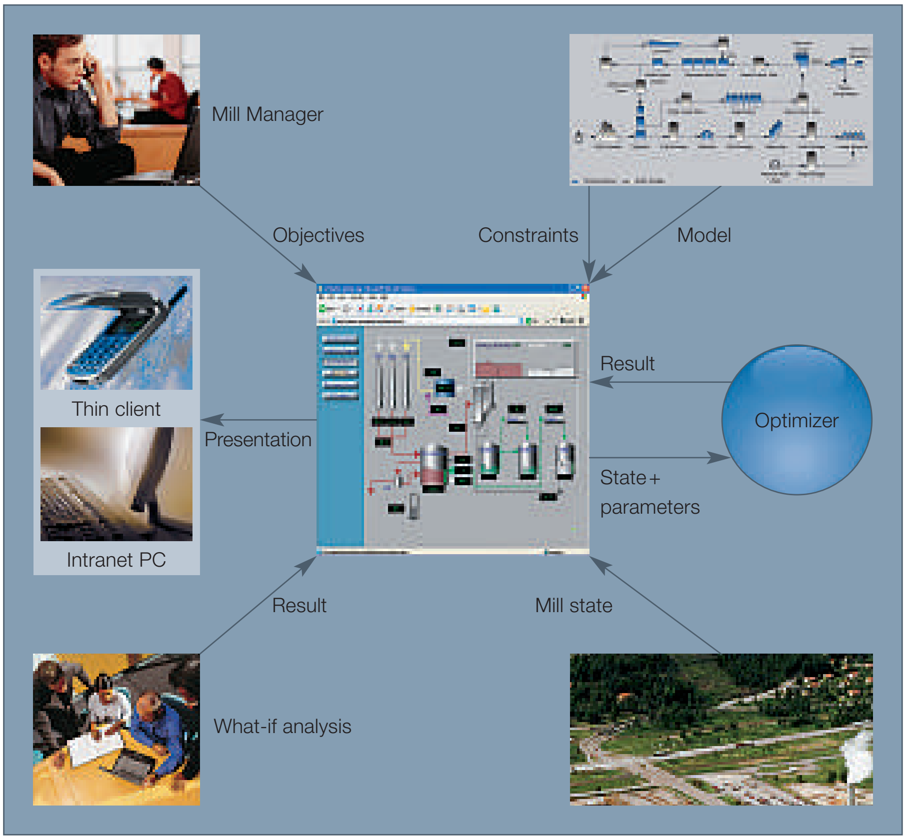
Pulp and paper mills consume considerable heat and electric power and hence energy management presents considerable potential for savings.

Each production unit consists of equations describing the time dependent relationships between all incoming and outgoing streams and manipulated variables connected to the unit. These relationships may be considered as a gigantic dynamic mass balance for the complete mill and are represented by a system of differential and algebraic non-linear equations. When these are discretized in time, the corresponding number of variables to be optimized can approach 50,000.

To be able to couple the process model to the measurements, a model of each sensor or lab measurement is required. The measurements are related to the state by using methods that consider both uncertainty of the models and the observations.

State estimation: To determine the current state, the sum of all measurement noises (uncertainties) is minimized. The noise levels at the optimum provide ex-

3 Multiple mill functions are considered in the optimization.



cellent information for sensor or process diagnostics. Noise values are tracked in the database and are used to identify faulty sensors or model refinements.

Optimization: The production-planning problem is formulated similarly to a model predictive control problem. The optimization criteria consist of different terms, quadratic and linear, and include terms to enable the following functions:

1. Minimization of deviation from set-point trajectories of any variable. One example is the paper machine production plan with its production rates and recipes. These set-points are automatically imported from the scheduling system. The paper machine is often re-scheduled at two-hour intervals. Other common examples are tank level set-points and preferred concentrations of active production chemicals.
2. Limiting the number of changes of the manipulated variables. Too many adjustments of manipulated control variables, as for example production rate in lime kiln, are to be avoided.
3. Minimization of costs (such as make-up chemical cost).
4. Maximizing revenues from main products and byproducts. One example of byproduct may be power production supplied to the grid.

The optimization criterion is minimized subject to the following constraints:

1. Process model.
2. Sensor model.
3. Upper and lower bounds on variables. A maintenance stop is introduced in the optimization by adjusting the upper bound of the production rate during the stop time for a production object, eg, digester.
4. Upper and lower bounds on change of manipulated variables. Changes in the manipulated variables are sometimes bounded by hard constraints to avoid causing overly aggressive trajectories. For example, a digester should not change its production rate at more than a given rate.
5. The production planning should start from the current value of the state estimation.

> The ABB 'On-line optimizer' is a very powerful tool for process control and decision support and is expected to contribute to significant improvements in the process industry for years to come.

The optimization results are used as a basis for production planning.

Simulation

Following the optimization, a simulation is performed. This provides an indication of the effectiveness of the strategy and predicts how long the process can run before tanks over- or under fill, production goals are missed etc. This simulated trajectory is compared to the original plan.

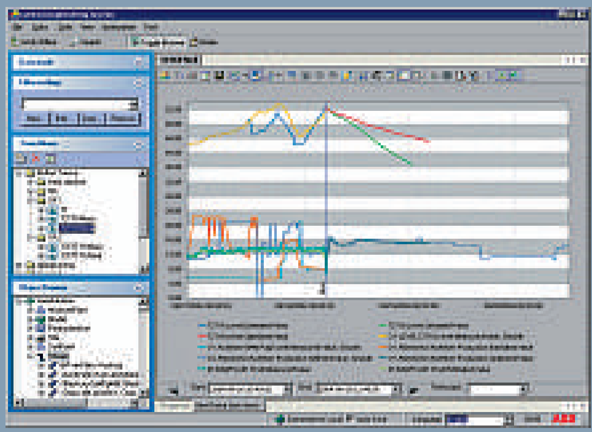
On-line Optimization

The automatically scheduled calculation 3 includes a state estimation, future optimization and a simulation. This cycle is repeated approximately four times an hour.

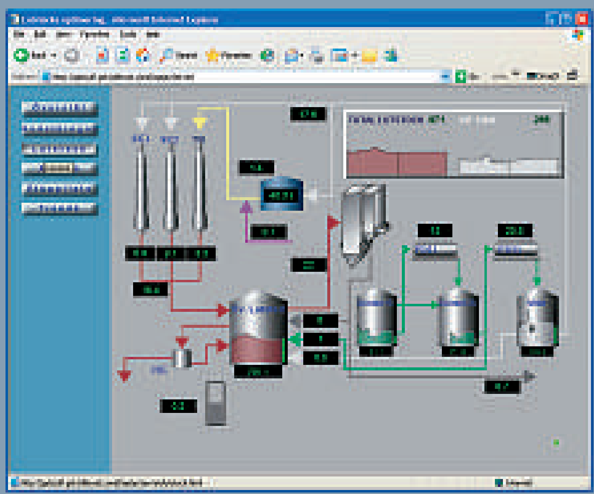
What-if analysis: Several what-if analyses can be started at any time on historical or future scenarios to evaluate alternative strategies and paths.

Solution Output: In the engineering user interface, many aspects of the model can be changed and all property values from measurement, estimation, optimization or simulation viewed. A customized trend view with many history and future data of given properties is generated in a couple of minutes and the trend configuration can be saved for later use 4. As soon as a trend view is created, any user can access this on the intranet web 5.

4 Customized trend describing issue in focus



5 Web-based graphical display with some common properties published on the customer intranet.



From the web based user interface the most important computation result may be viewed from any PC connected to the mill intranet or internet. It is also possible to perform the most important interaction with the system through this interface, e.g. information of maintenance stop duration and stop time etc.

Client expectations

Benefits:

- Increased paper production.
- Savings in make-up chemicals.
- More stable quality of active production chemicals.
- On-line identification of production bottlenecks easily viewed by the web based user interface indicating current and future bottlenecks.
- Improved decision support for production management. When operation decisions must consider many secondary conditions in the mill, the on-line optimizer provides invaluable alternative scenarios for production.
- Common operation strategy for all shifts and control rooms. By using the on-line optimizer, operation management can systematically prioritize between different objectives and targets. When the preferred prioritization is configured in the database and the optimizer's recommendation adopted, it is easier to motivate the operation strategy than before.
- More efficient preparation of the mill prior to maintenance stops is desirable. When a maintenance stop is introduced in the prediction horizon, the optimizer automatically considers this constraint to minimize production loss. It is also possible to evaluate a change in maintenance stop time and quantify the consequence of a longer than expected stop.
- Identification of faulty measurements by using state estimation diagnostic results.

This is a brand new product in ABB's portfolio. The on-line production optimizer employs new and advanced methods, capitalizing on the impressive evolution in computing power. Large mill systems including the complete chemical balance and energy management coupled with dynamic production rates can now be optimized in real time using a large number of on-line measurements. The optimizer uses general methods, which is why it can easily be applied to other applications or system types. The on-line production optimizer is also 'the missing link' between advanced process control and CPM (Collaborate Production Management system) to support the planning function for the integrated Pulp & Paper mills. The ABB 'On-line optimizer' is a very powerful tool for process control and decision support and is expected to contribute to significant improvements in the process industry for years to come.

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