Energy Conservation through Automation of Processes in Pulp and Paper industry

Manish Maheshwari and Rajesh Sahasrabudhe

Paper industry is one of the most highly capital and energy intensive industry. It has been identified as one of the fifteen most energy intensive industries in India which have been named as designated consumers in Energy Conservation (EC) Act 2001. It is the sixth largest consumer of electrical energy in the country. The main emphasis in the EC act is to monitor and reduce specific energy consumption in the industries. Besides this, rising energy prices are driving up costs at every manufacturing plant.

Energy cost accounts for approximately 20 - 25% of the total manufacturing cost in a paper industry. Energy consumption in paper industry in India is very high in comparison of developed countries. This can be attributed to low level of automation and not very energy efficient processes. The paper manufacturing plant comprises raw material preparation section that is wood chipping, pulping, bleaching, washing, evaporation, drying, and paper making. These represent a diverse range of unit operations from relatively simple operations like chipping to complex operations like digestion, bleaching, evaporation and paper making. These unit operations are highly energy-intensive with significant impacts on the overall economics of paper manufacturing.

Most of these unit operations due to their complexity are difficult to control and run under conditions of high process variability. This process variability is a major source of inefficiency and results in higher energy consumption. A control strategy which can adapt to different operating conditions, be able to predict the process performance, and minimize the process variability will give maximum energy efficiency.

Moreover these processes are highly inter-dependent and efficiency of one process affects the efficiency of its downstream processes. As an example, if Kappa number is not reduced in digester it will affect the efficiency of bleaching operation which may result in the reduction in output. This puts an additional requirement on the control strategy that it should not only maximize the energy efficiency of the process that it is controlling, but also should optimize it in such a way that its process output conditions do not result in additional burden on the downstream processes. So it is very essential to control the processes at different stages to the optimum so maximum throughput can be achieved across all the operations with minimum overall specific power consumption.

Paper plants not only consume energy but also generate waste in the form of weak black liquor (WBL). Concentration of WBL in heavy black liquor in evaporators and its subsequent burning in boilers allows paper plants to generate steam which can be used either as process steam or as source of power generation. Carefully designed control strategies are necessary to operate evaporators and boilers in such a way that maximum energy can be generated from the WBL.

This paper discusses advanced control techniques which can be used for energy optimization of unit operations in pulp & paper plants. These techniques make use of process knowledge in the form of process models and use them in predictive manner to control the variability of the process to achieve optimum performance. Application of these techniques to various unit operations such as digesters, bleaching, entire recovery island is also discussed in details.

In this paper, a description, from better control point of view, of these processes is presented. As a result of which processes are operated at close to their optimum levels. This helps in increasing throughput and reduction in specific power consumption.

INTRODUCTION

Paper manufacturing consists of feed preparation, pulping, washing, bleaching, paper making processes and recovery section. These represent a diverse range of unit operations from relatively simple size reduction operations to complex digestion and paper making processes. Pulp and paper industry is capital and energy intensive industry, overall operational objectives for pulp and paper plants are:

- Optimal capacity utilization,
- Reduction in specific energy consumption,
- Reduction in variability in product quality,

Advanced Process Control Group, Engineering & Industrial Services, Tata Consultancy Services Ltd. 1, Mangaldas Road, Pune-411 001

- Smoother operations with increased uptime,

Due to energy intensive industry it remains a priority of the plant to operate plant at optimum level with minimum possible specific energy consumption. The main characteristics of processes and challenges in controlling these processes in a paper plant are:

- Combination of continuous & batch processes
- Long process chain – many unit operations
- Large lag times
- Raw material composition variability
- Interdependent operations
- Multivariable interactions in almost all the operations
- Lack of measurement available for key quality variables like Kappa number in digester, brightness in bleaching, calcination in kiln etc.
- Large scale of chemical recovery operation

In processes like digester, evaporator and boiler sections, the critical variables oscillate or tend to oscillate more than desired. These processes usually do not operate in a regular and stable manner, not at its maximum point of efficiency. However, this is not surprising, given the control difficulties these processes involve, due to their dynamic nature.

Automation of processes by implementing model based advanced control strategies are well suited to handle these problems. These control strategies not only operate plants at their optimum levels by reducing process variability but also helps in improving quality of the product. This paper describes how advanced control solutions can be implemented with an objective of reducing specific energy consumption in a paper plant. These solutions are designed to optimize the performance of individual units with targets appropriately driven by the overall operational objectives (optimum capacity utilization and reduce specific energy consumption) for the plant.

2. Pulp and Paper plant overview

Pulp and Paper plant is a mixed process plant with some processes are operated in continuous mode and some in batch mode. In feed preparation section, wood is de-barked and cut (chipped) in to smaller size. Chips are fed in the digesters and fibers are separated and lignin is removed. Oxygen delignification removes lignin from the brownstock as a pre-bleaching step. Pulp washing takes place after each major process. The purpose of washing is to remove undesirable elements from the pulp stream. Pulp bleaching is normally done in a step-wise sequence using different chemicals (e.g. CO_2, H_2O_2, ozone, oxygen) and process conditions at each stage, with washing in between stages. Then the paper is processed in press and dryer and pressed in the calendar section and rolled into parent rolls. In chemical recovery section the used pulping chemicals are separated from the wood waste and used for making white liquor while as the weak black liquor is concentrated in multiple effect evaporators and is burnt in the boiler for generating steam. This steam is either used as process steam or used for generating power.

The overall specific energy (steam/ power) consumption norms, for large integrated paper plants, producing writing and printing paper, using 100% wood pulp based sulphate process, are as follows:

- Steam: 8.00 tons/ton of finished paper
- Power: 1300 KWh/ton of finished paper

The break-up of specific steam consumption (t/t of finished paper) in different section of the plant is as given below. Approximately 50 % of the total steam consumed in the plant is consumed in evaporator and paper making sections.

The break-up of specific power consumption (kWh/ton of finished paper) in a typical paper plant is as given below.

It is clear from the table data mentioned above that steam and power consumption are major sources of energy consumption in pulp and paper plant. Plants are making all the efforts by optimizing the operations and installing energy efficient equipments like VFDs/ on-line monitoring of flue gases to control excess air/ Sodium Vapor lamp fittings etc to reduce

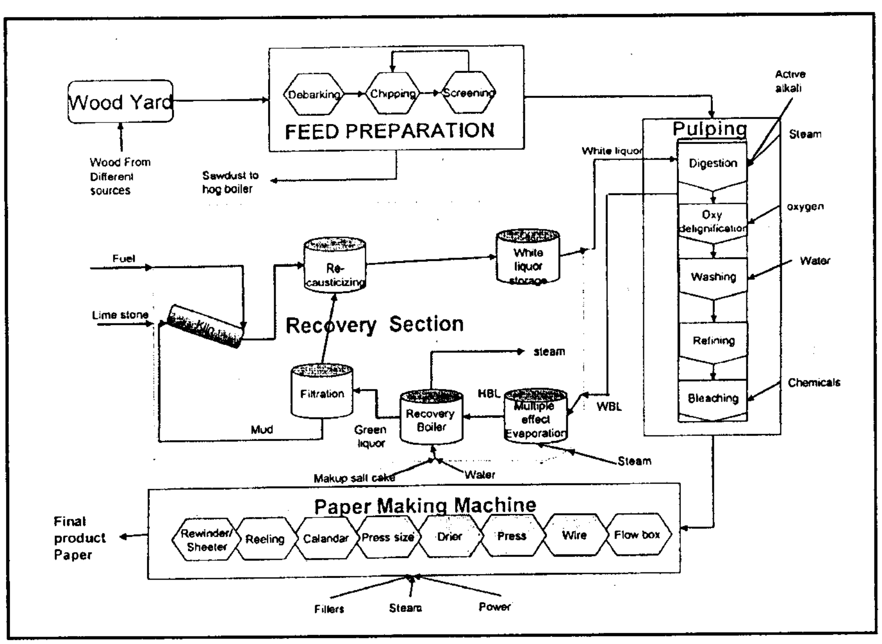
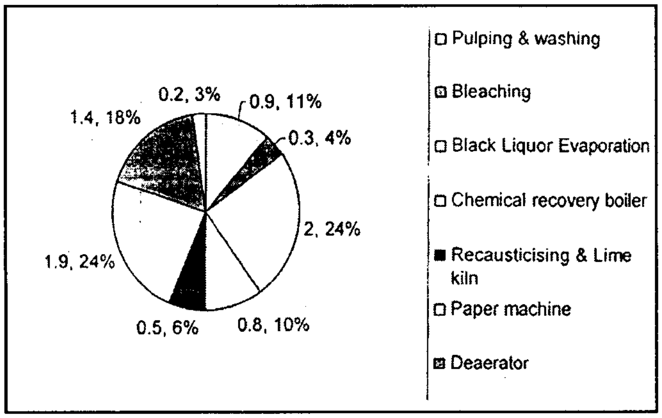
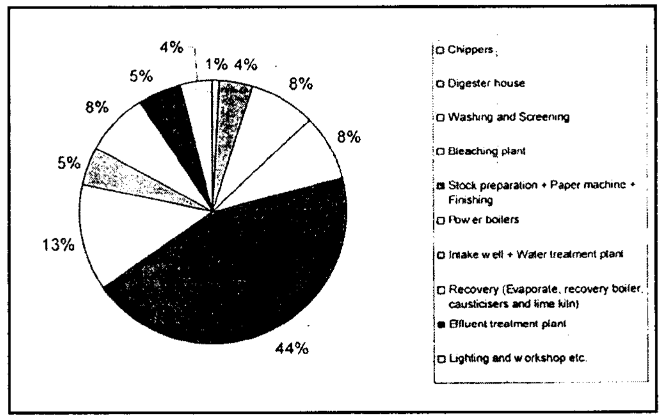


Table 1: Break-up of steam consumption in pulp and paper plant *



*-Reference-http://greenbusinesscentre.com/paperintro.asp

Table 2: Break-up of power consumption in pulp and paper plant *



*-Reference-http://greenbusinesscentre.com/paperintro.asp

specific power consumption in their plants.

In addition to these measures, additional energy reduction and productivity gains can be achieved to the tune of 1 – 5 % by automating the processes that is by implementing Advanced Process Control (APC) solutions. The APC solution continuously monitors a number of key process variables minute-by-minute, predicts output based on a model of the process, simulates the impact on the plant's objectives (increased throughput, reduced specific energy consumption, quality) and then calculates the optimum set points for key inputs and downloads the set points to the DCS/PLC/SCADA to make changes to the key process variables that are driving results.

3. Advanced Process Control Solutions

Advanced process control solutions use Model Predictive Control (MPC) technique, fuzzy logic and neural network techniques for controlling and optimizing processes. MPC has increasingly been used to control and optimize the operations, which considers the prediction of the variables evolution and the application of control actions according to what is desired. MPC is a descriptive name for a class of computer control scheme for the explicit prediction of future plant behavior. It computes the appropriate control action required to drive the predicted output as close to target value as possible. In other words, process inputs (manipulated variables set point) are computed so as to optimize future plant behavior over a time interval known as the prediction horizon. Generally, any desired objective function can be used. Plant dynamics are described by an explicit process model, which can take, in principle, any required mathematical form. Process input and output constraints are included directly in the problem formulation so that future constraint violations are anticipated and prevented. The first input of the optimal input sequence is injected into the plant and the problem is solved again at the next time interval using updated process measurements. Control strategy can also use soft sensors for predicting quality parameters like calcination in kiln section and has a mechanism to incorporate periodic corrections to the predicted values.

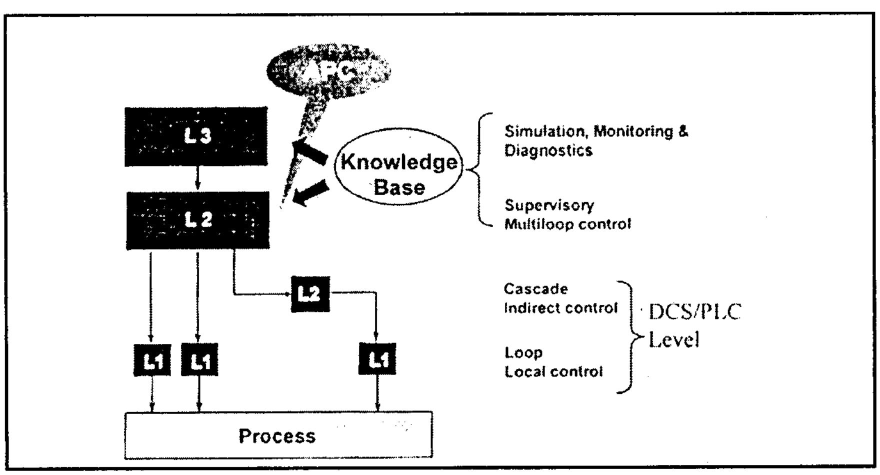


Fig. 2: Advanced Process Control solution's position in automation hierarchy

Table 3 lists the benefits that can be achieved by implementing advanced control systems in digesters and recovery sections.

APC based control strategies for recovery and kiln sections have been discussed below.

4. Application of APC in recovery & kiln sections

The process description, challenge in control and control philosophy for waste heat recovery section that is black liquor evaporation and boiler plant is described below. The main benefits that can be achieved by implementing APC in recovery section are:

Table 3: Benefits achievable by implementing APC solutions in Digester and Recovery sections

Processes	Benefits
Continuous Digester Optimization	Stabilize the process Provide consistent operation from shift to shift Minimize pulp quality variation – K/Kappa Enable operations to control kappa shifts Reduce wood, chemicals, and energy consumption
Batch Digester Optimization	Minimize variations in pulp quality, Increased digester yield Reduce Chemical Usage, Reduced cook cycle and idle times, Reduced steam consumption, Level steam flow variations
Multiple Effect Evaporators	Improved Stability over Wide Operating Rage Thermal Efficiency Increase, Better Solids Control Reduced Water Load
Recovery Boilers	Increased Throughput, Increased Thermal Efficiency, Improved Green Liquor Reduction, Reduced Pollutants, Reduced Process Variability.
Soot blowing	Reduced Steam Use, Reduced Steam Demand
Lime Kiln	Reduced Variation in Residual Carbonate, Reduced Fuel Consumption, Increased Process Stability from Shift to Shift, Increased Production Capacity, Increased Efficiency Controlled Emissions, Improved Equipment Protection, Improved Lime Quality.

- Improved Stability over Wide Operating Rage
- Thermal Efficiency Increase
- Reduced Process Variability
- Better Solids Control
- Reduced Water Load
- Reduced Pollutants

Black liquor evaporation

Black liquor evaporation plant is one of the major consumers of steam in paper mill. The steam consumption depends on the number of stages at the evaporation section. Normally there are 6 to 7 evaporation stages. The final product is called as heavy black liquor (HBL). The average HBL concentration leaving the evaporators is about 50%. Some mills have achieved a black liquor concentration at the outlet of evaporators as high as 65 - 70%. The control strategy in a given plant should be like that it produces maximum concentration of heavy black liquor from evaporators so that the energy efficiency of recovery section is maximised and more steam can be produced.

Recovery boiler

HBL consists of both inorganic and organic solids. The inorganic solids are predominantly the un-reacted chemicals in digestion & organic solids are lignin from wood. This HBL is fired in the recovery boiler. The organic part burns and the inorganic solids melt. This melt is drawn out from the bottom of the boiler as smelt. So, the main aim of the recovery boiler is to recover the un-reacted chemicals and at the same time produce steam for power generation. At recovery boiler, the steam generation per tonne of black liquor solids depends on the concentration of black liquor entering the boiler. Present average steam generation is only 3 t/t of black liquor solid (with 45% concentration black liquor entering the boiler). The steam generation increase with increased concentration of black liquor is as follows

Black liquor concentration (in percentage)	Steam generation * (t/t of black liquor solid)
45	3.0
65	3.4
85	3.8

* - Reference - http://greenbusinesscentre.com/paperintro.asp

Therefore, there exists a good potential for increasing the steam generation by at least 13% (from 3 to 3.4 tonnes of steam per tonne of fuel) by improving the black liquor concentration at the evaporator. In the process there is high variability in steam generated to solid contents in the feed to boiler. With advanced process control not only the variation can be reduced but also the steam to solid ratio can be increased close to constraints without exceeding the limitations. So, by implementation of advanced process control for Recovery boiler and Falling Film multiple effect Evaporator (FFE) efficiency of recovery boiler can be increased.

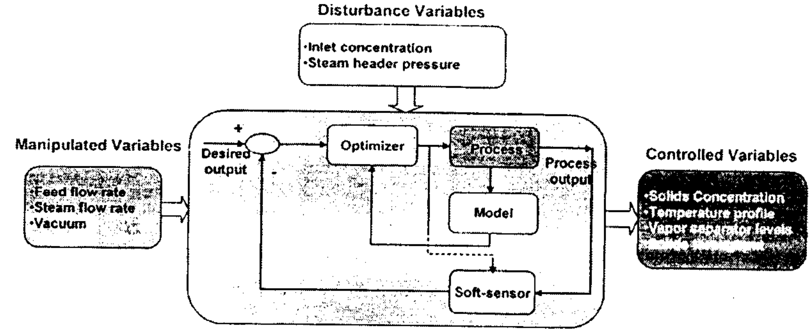
Control Philosophy

The main objective of APC solution for evaporator and boiler is to increase thermal efficiency that is to increase steam generation.

The **Evaporator APC** controls simultaneously HBL solids, key vapor separation temperatures and levels, and the solids throughput. The manipulated variables are steam flow and pressure, WBL flow and the vacuum. WBL inlet solids concentration is treated as a disturbance variable.

The following figure indicates the control strategy for evaporator system.

The **Recovery Boiler APC** controls simultaneously steam superheat



TYPICAL CONTROL STRATERGY FOR EVAPORATRS

Figure 3 : Block Diagram of the control strategy

temperature, steam pressure, furnace draft, solids throughput, and the O_2 concentration. This is done by manipulating HBL flow, feed to air ratio (primary, secondary and tertiary air), soot blowing steam pressure and flow, de-super heater water flow and the ID fan speed.

- The controller takes appropriate corrective actions to handle disturbances coming from variations in HBL solids.
- The controller controls the excess combustion air to the optimum so that combustion is complete with minimum excess air and maximum thermal efficiency is achieved.
- The controller stabilizes firing by compensating for changes in black liquor quality and composition.

Kiln APC

The main operations in the kiln are: drying, increasing temperature, and adding heat to sustain calcining reaction. The kiln APC controls the feed rate, fuel rate and ID/FD fan RPM, Kiln RPM and maintains the calcination of the product and the flue gas O_2%.

- Controller takes appropriate action for varying fuel rate based on the moisture % and feed rate
- Controller maintains air to fuel ratio to the optimum so that the fuel is burnt completely with minimum excess air in the flue gases
- Controller takes appropriate action to maintain the draft within the target with minimum KWh requirement on the ID or FD fans
- Controller takes appropriate action to control the burn end and feed end temperature thereby maintaining the calcination in the kiln

The following benefits are achieved by implementing kiln APC:

- Reduced Variation in Residual Carbonate
- Reduced Fuel Consumption
- Increased Process Stability from Shift to Shift
- Increased Production Capacity
- Increased Efficiency
- Controlled Emissions
- Improved Equipment Protection
- Improved Lime Quality

5. CONCLUSION

The pulp and paper industry is capital intensive, energy intensive and environment sensitive. So by implementing the APC systems maximum capacity can be extracted from the plant without making any capital expenditure. APC coordinates a large number of parameters to maintain control closer to operating constraints and more favourable economic operating conditions. By reducing process variability, APC is able to push operations to run at conditions that increase throughput, improve product quality, reduce energy and raw material usage, and increase operational efficiency. The improvement from implementation of APC systems could be to the tune of 1 – 5%.