OPTIMUM STEAM PLANT EFFICIENCY THROUGH ADVANCED CONTROLS AND ENERGY DASHBOARDS

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ABSTRACT

Operating a mill's boiler and steam system for maximum profitability has become challenging due to increased complexity in power contracts and high variability in fuel costs. The objective of this paper is to examine the technical, economic, and process-related challenges in achieving efficient operation of a plant's energy system. Additionally, this paper will present examples of different cost-reduction projects where advanced automation technologies were utilized.

INTRODUCTION

Most large pulp and paper mills have power and steam generation onsite to reduce operational cost as well as to provide “operational insurance” in the case of a power disturbance from the grid. As a result, pulp and paper mills require a sophisticated balance between power generation, purchased power, and power usage to balance loads throughout the plant and ensure safe, reliable operations. In recent years, due to the increased price volatility of power and fuel, the optimum operating scheme for a utility plant will change on an hourly basis. As a result, a plant can take advantage of this fuel and electricity profitability to reduce its operating costs and increase overall steam plant and boiler availability.

INTERNAL POWER GENERATION: AN ADDITIONAL DEGREE OF FREEDOM FOR INCREASING PROFITABILITY

Pulp and paper mills are equipped with steam distribution systems, which have the capability to capture thermal energy and transform it into electrical energy using steam turbines. To demonstrate the concept, Figure 1 shows a simplified diagram of a steam distribution system comprised of multiple high-pressure headers (1250 and 600 psig header) and two steam turbines. When steam turbines are not available, the high-pressure steam is fed from the boilers into pressure reducing valves (PRVs) to reduce the high pressure steam into medium or low pressure steams to be used by mill processes.

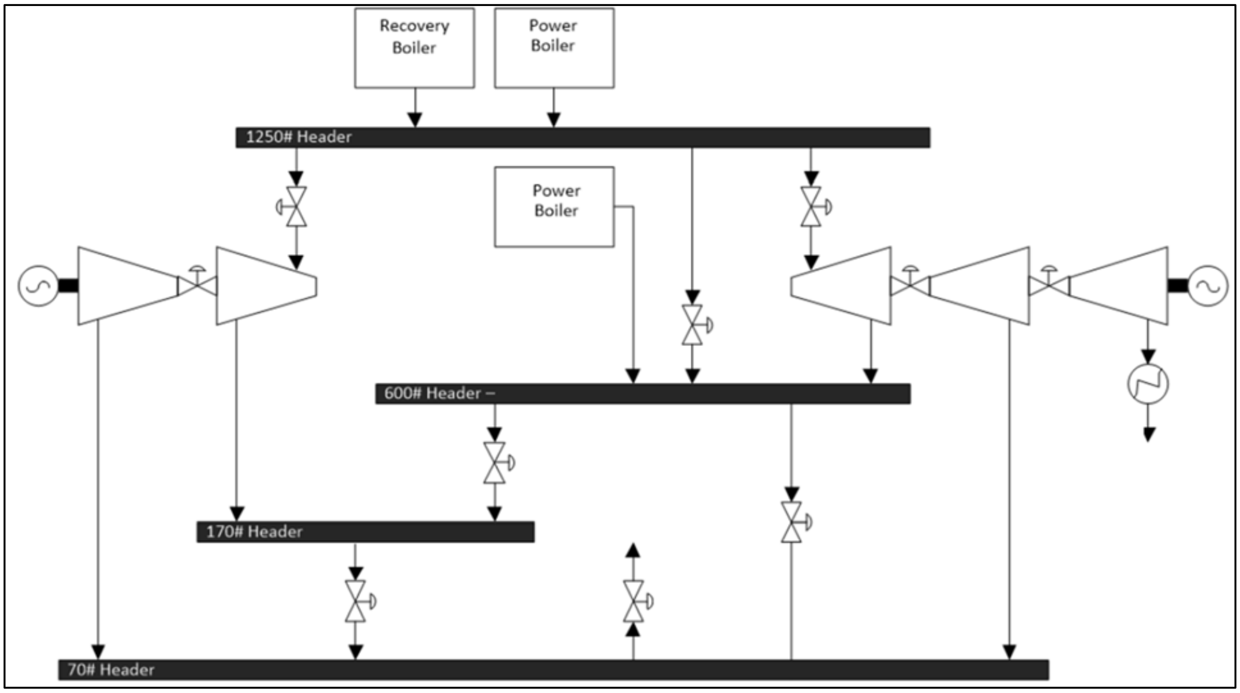


Figure 1: Simplified steam cogeneration system

The following input variables are needed to determine the most profitable turbine operational strategy for a mill's cogeneration system:

1. Fuel cost and boiler efficiency will determine the cost of steam per fuel for each boiler.
2. Turbine thermal-to-power efficiency (heat rate) will determine the capability of steam turbines to convert thermal energy into electrical power.
3. Power contracts will determine the cost of electricity to the mill.

Fuel cost and turbine thermal-to-power efficiency will determine the breakeven points where generating an additional megawatt of power leads to reduced overall mill profitability. Figure 2 shows an example of four different Steam Paths for an integrated kraft mill with their corresponding power cost for a fuel cost of 10 $/MWh:

- Electrical power generated through cogeneration is calculated at 13 $/MWh
- Electrical power generated through cogeneration is calculated at 54 $/MWh
- When the still turbine condenser has reached its maximum capacity (or when the turbine has no condenser), additional power can be generated by venting lower-pressure steam at a cost of 97 $/MWh

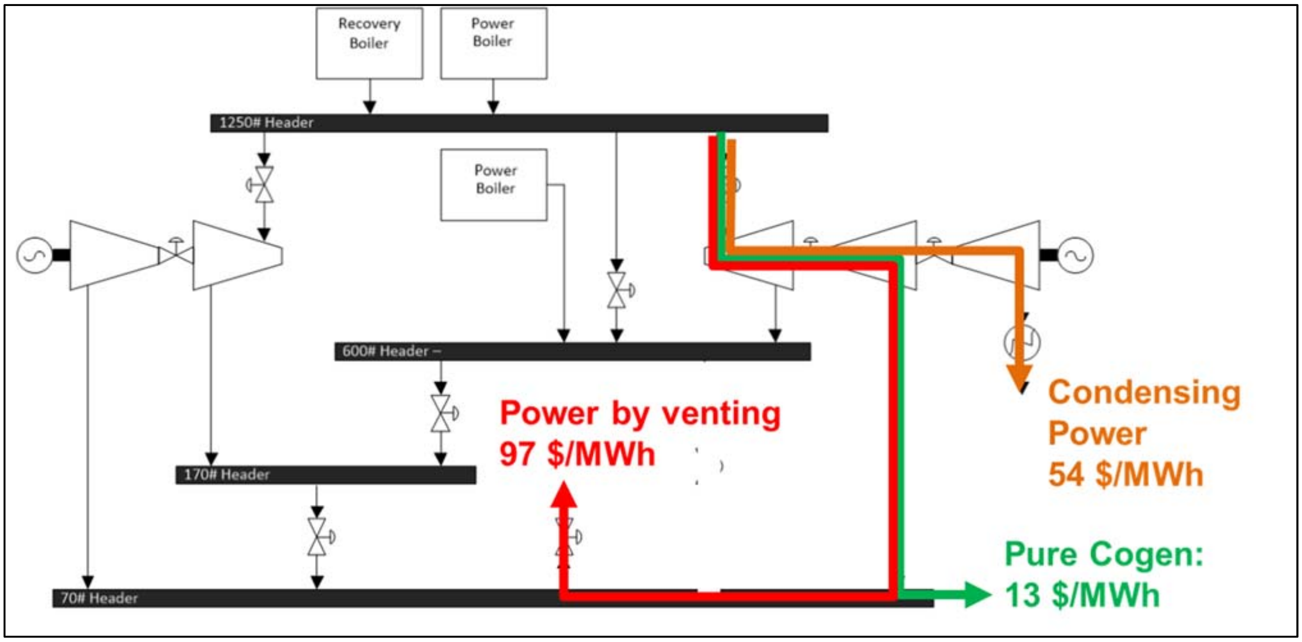


Figure 2: Example of Steam Paths with their corresponding power cost

Using the same example, a simple steam operating strategy can be established:

1. When the price of power is under 13 $/MWh, purchasing power from the grid should be maximized and internal power generation should be minimized. (the steam bypass valves should supply the process to operate the turbines at their lowest load).

2. When the price of power is under 54 $/MWh, cogeneration power is the only form of profitable power generation. In this scenario, the difference between the total power demand from the mill and cogeneration power should be purchased from the grid.

3. When the price of power is under 97 $/MWh, cogeneration power and condensing power is profitable and boiler firing rate should be increased to maximize steam turbine condensing capacity.

4. When the price of power is extremely high (above 97 $/MWh) venting steam to generate electricity is profitable.

COGENERATION OPTIMIZATION AND THE DUCK CURVE

Once the cost of fuel is known, the cost of generating power can be calculated and economic-based decisions can be taken on increasing the boiler firing rate to internally generate additional power. This additional generated power is then used to either reduce the amount of power purchased from the grid or increase the amount of power sold to the grid.

Four cogeneration operating strategies are typically available to a plant:

1. When the price of electricity is very low relative to the price of fuel, purchasing power from the grid should be prioritized.

2. When the price of electricity is ‘normal’ relative to the price of fuel, power should only be generated using cogeneration (i.e.: power generation is a function of steam demand from the users).
3. When the price of electricity is high relative to the price of fuel, condensing power generation should be maximized.
4. When the price of electricity is very high relative to the price of fuel, the mill should maximize power generation through steam venting or condensing.

The most common operating strategies for a pulp and paper mill involve either maximizing cogeneration (Operating Strategy #2) or a combination of maximizing cogeneration and condensing power generation (Operating Strategy #3). The challenge of running an industrial cogeneration steam system at maximum profitability are that variables affecting the operating strategies listed above vary over time. For example, the price of electrical power is not static but rather fluctuates throughout the day, a phenomenon often attributed to what is known as the "duck curve." The duck curve which is shown in below is a graphical representation of electricity demand over a 24-hour period, which resembles the profile of a duck, with a deep midday trough and rising evening peak. The effect of additional renewable solar power can also be seen on the duck curve with a steeper decline in net power demand in the middle of the day when large amount of solar power generation is produced.

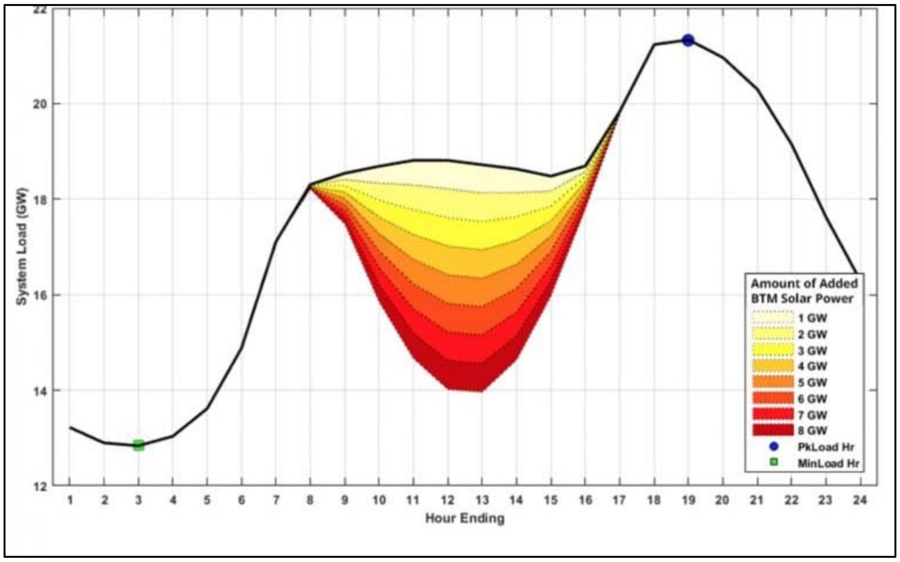


Figure 3: Example of a ‘duck curve’ with system load vs. time and the impact of renewable energy

The duck curve is primarily a result of several factors from human behavior to energy availability. Energy demand will typically be a function of society’s need with an increased demand in the morning, a high demand in the afternoon and a falling demand at night. The integration of renewable energy sources, such as wind and solar, has introduced a variability into the grid and has exacerbated the power price fluctuations where the cost of power can vary considerably throughout the day.

Figure 4 and Figure 5 shows that two examples where the mill operating strategy will need to be modulated as a function of the grid demand:

- Figure 4 shows a daily grid demand with a duck curve that is not too pronounced and where an overgeneration strategy is only needed in the afternoon. In this case, the mill should shift its operating strategy twice a day from turbine condenser minimization to turbine condenser maximization.
- Figure 5 shows a daily grid demand with a pronounced duck curve where an overgeneration strategy will be

needed in the morning and in the afternoon. In this case, the mill should shift its operating strategy four times in a day from turbine condenser minimization to turbine condenser maximization.

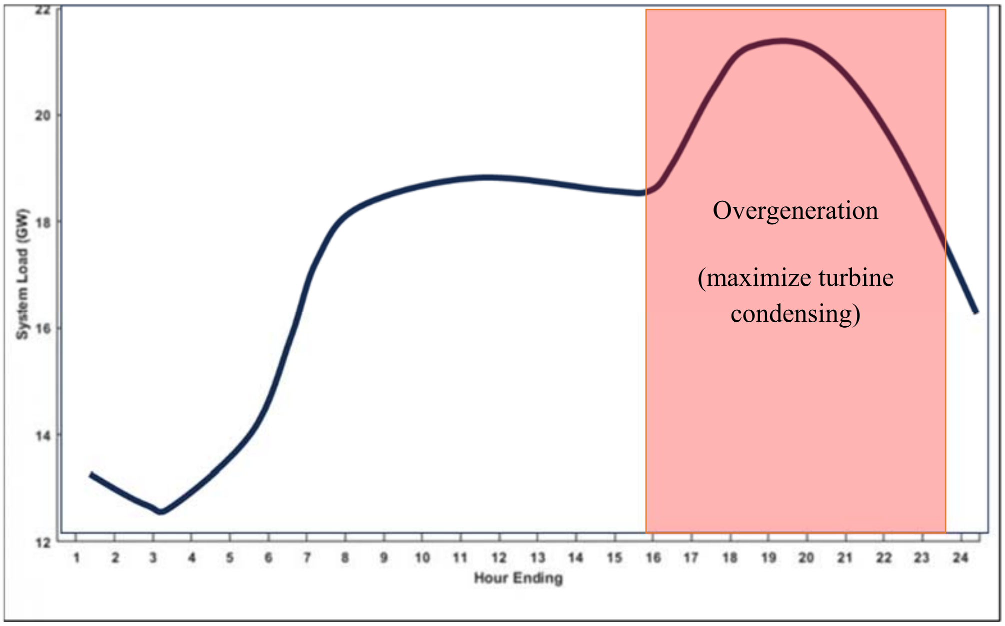


Figure 4: Example of a 'duck curve' with one period of overgeneration

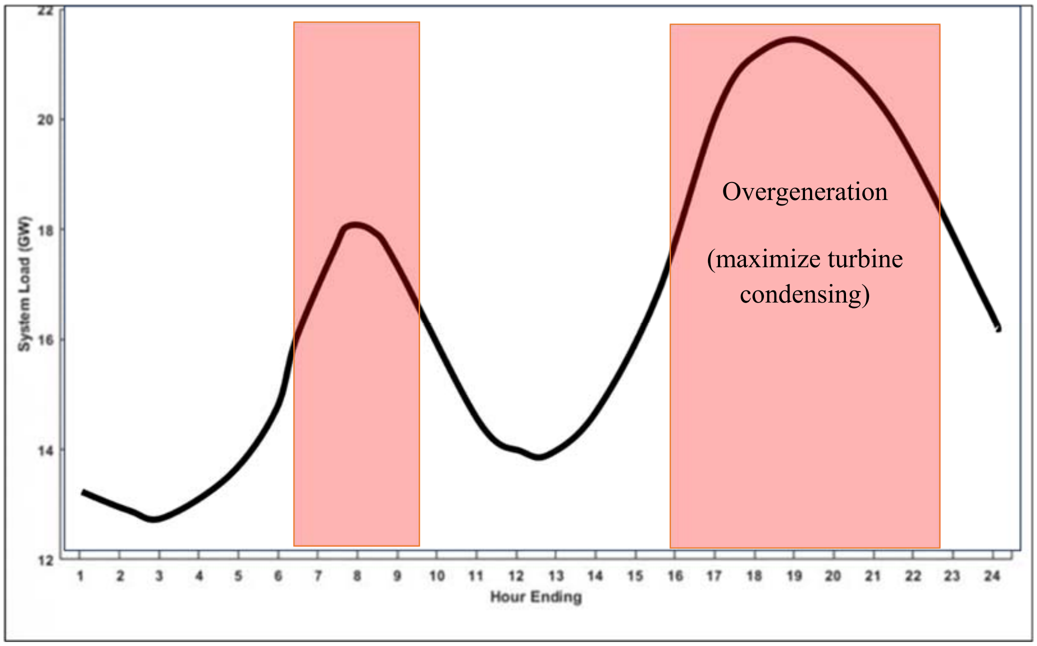


Figure 5: Example of a 'duck curve' with two periods of overgeneration

TRACKING OPTIMUM POWER GENERATION USING ENERGY DASHBOARDS

The amount of power generation available through cogeneration and maximum condensing power is typically related to the process steam demand - when the steam demand increases, profitable power generation will rise. However, potential power generation can be limited by a number of factors such as boiler firing rate limitation, steam turbine constraints, control valves in manual, etc. Tracking these constraints to inform the operators on how to run the steam plant can be done using a dedicated Energy Dashboard where ideal operation is compared with the existing operation and alarms are set when deviations are too large.

The Energy Dashboard will have the following building blocks (see Figure 6):

1. Plant process data coming from the plant control system or historian are used as input variables for the Dashboard. Critical inputs are mill steam demand, PRV mode, boiler mode, turbine mode, fuel cost, power cost, etc.

2. A process model (Digital Twin) receives the different process information and generates the optimum operating scenario using a thermal and economic model of the steam plant.

3. An operator interface is used to inform on best operation and provide alarm on deviation.

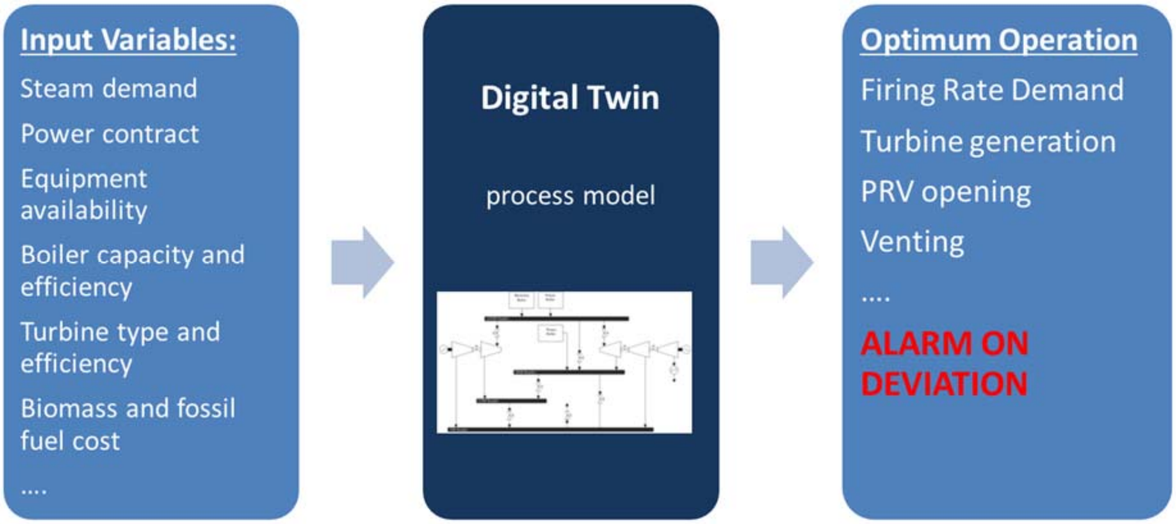
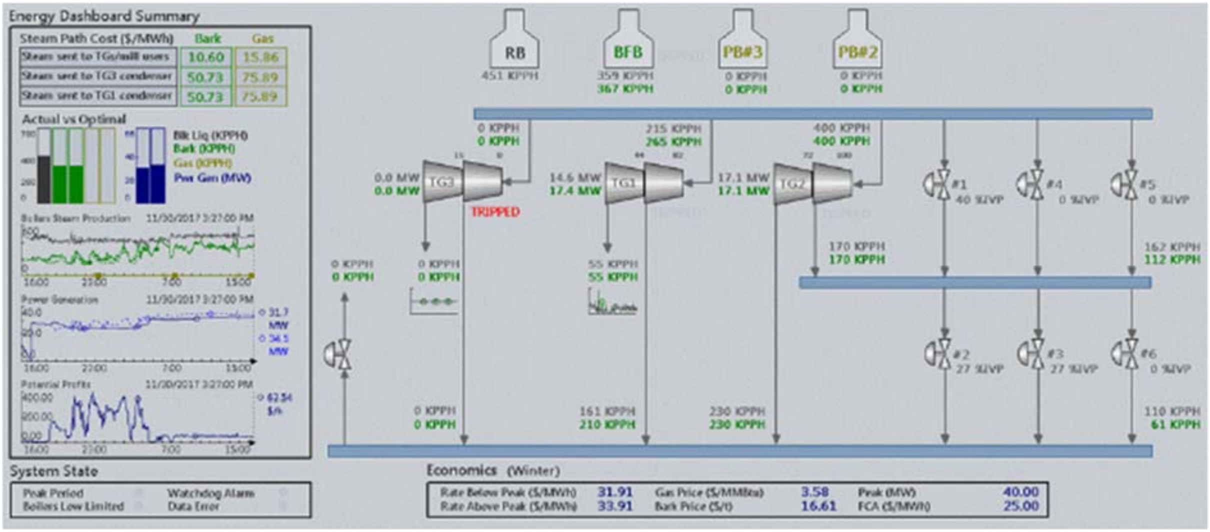


Figure 6: Building blocks of a Steam Dashboard

An operator interface for a Steam Dashboard is shown in Figure 7:



Energy Dashboard Summary

Steam Path Cost ($/MWh)	Bark	Gas
Steam sent to TGs/mill users	10.60	15.86
Steam sent to TG3 condenser	50.73	75.89
Steam sent to TG1 condenser	50.73	75.89

System State

Peak Period
Boilers Low Limited
Watchdog Alarm
Data Error

Economics (Winter)

Rate Below Peak ($/MWh)	31.91	Gas Price ($/MMBtu)	3.58	Peak (MW)	40.00
Rate Above Peak ($/MWh)	33.91	Bark Price ($/t)	16.61	FCA ($/MWh)	25.00

Figure 7: Steam Dashboard

STEAM DASHBOARDS, ADVANCED STEAM CONTROLS AND RELIABILITY

Steam dashboards can offer operators sufficient information and valuable insights. However, following the optimal operating strategy solely through an advisory 'open-loop' process becomes challenging when real-time minute-to-minute adjustments are necessary. For mills seeking continuous energy optimization, it is advisable to implement a closed-loop steam header control system. The author has implemented a number of different advanced process control (APC) solutions for pulp and paper mills. The solution programmed in the mill DCS or PLC was executing every 500 milliseconds. At every execution, the APC would go through the following steps similar to the Steam Dashboard:

1. Determine the specific flow demand for each steam header,
2. Calculate the most profitable path based on power cost, fuel cost and turbine constraints.
3. Determine the constraints for the different paths (valves in manual, turbine tripped or constrained, etc.).
4. Feed the different steam headers with the required amount of steam flow using the most efficient path in monetary order.

With this control scheme in place, the optimization and profitable path switching can be done at every step without disturbing the steam flow to the headers hence ensuring optimum steam pressure stability.

Although the implementation of APC technologies will typically have a ROI value of less than 6 months, the main challenge for mills is to ensure that the APC remains in automatic. From past experiences, important factors will influence the success of an APC implementation:

- APC is capable at keeping the steam system running when a large disturbance occurs (if the mill trips when a turbine trips, the operator will typically turn the APC off forever),
- APC is programmed in the plant DCS or PLC (PCs are not robust enough for critical asset control),
- Simulation is used to train operators prior to APC implementation,

- Simulation is used to thoroughly offline test the APC to ensure the code is bug free and responds well to real system disturbances (turbine trip, turbine island mode, boiler trip, etc.)
- Once an APC is installed, all steam system issues, real or perceived, will be blamed on the APC. To ensure long-term operator acceptance of the new steam controls, it is critical that the APC vendor provides online diagnostics that allow the operation group to quickly have answers to the following questions:
    - Is the APC making the correct control action but we don't understand why?
    - Are there instrumentation or mechanical issues that need to be fixed?
    - Is there a bug in the APC code and when can it get fixed?
    - How far from the optimum profitability point is the APC operating the system at?

CONCLUSION

Cogeneration plants in a pulp and paper mills are highly complex and can be operated using different operating philosophies. Unfortunately, changes in variable fuel cost, steam plant constraints and variable power rates lead to a continuous change in the optimal steam system operating philosophy. Advanced controls with online profit optimization is the best tool that can automatically switch steam system operating strategies online to follow the optimum profit target mode.

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