Case Study of Optimal Byproduct Gas Distribution in Integrated Steel Mill Using Multi-Period Optimization

KIMMO MÄKINEN
BUSINESS MANAGER

TONI KYMÄLÄINEN
PRODUCT MANAGER

JAAKKO JUNTTILA
SALES MANAGER

ABB OY
HELSINKI FINLAND

ABSTRACT

Energy constitutes about 20 % of the total production cost in an integrated steel mill, and therefore energy efficiency is crucial for profitability within the environmental policy context.

An integrated steel mill generates high calorific value byproduct gases at varying rates. The differences between gas generation and consumption rates are compensated with gas holders. However, under certain circumstances the imbalances can lead to the flaring of excessive gas or require the purchase of supplementary fuel.

This presentation describes a steel mill energy management system with sophisticated monitoring, planning, and optimization tools. It models the complex energy interconnections between various processes of the mill and determines the optimal trade-off between gas holder level control, flare minimization, and optimization of electricity purchase versus internal power generation. The system reduces energy cost, improves energy efficiency, manages carbon footprint, and provides environmental reporting features.

INTRODUCTION

The principal energy flows between the various production sections in an integrated steel mill are outlined in the energy map in Figure 1.

Byproduct gases are generated in the primary reduction process in Blast Furnaces or Corex Furnaces, in coke ovens and in the steelmaking process in Basic Oxygen Furnaces. Gas holders are available for gas storage to compensate for the temporary imbalances between consumption and production rates. Surplus gas that cannot be used in the processes or in the power plant is flared and additional Natural Gas can be imported from the grid in case of shortage.

The power plant has steam boilers that can be fired with various combinations of fuels, including byproduct gases, imported natural gas, and byproduct or purchased liquid fuels. The steam produced in the boilers is used to generate electricity in the power plant and supplied to various consumers in the production sections, building heating, etc.

Most production sections will be consumers of the byproduct gases. Different users require different calorific values (compositions) resulting in use of gas from specific streams or from gas mixing stations.

All production sections consume electricity. Electric power is imported from the grid and generated in the mill power plant steam turbine generators or by blast furnace reduction turbine(s). Electric power may potentially be also exported.

As appears from the above, the different forms of energy consumed and generated at the plant are interconnected and interactive and should therefore be optimized together. The optimization calculates optimal byproduct gas distribution schedules to the consumers in the production sections and to the boilers in the power plant. The optimization will maintain the levels of the gas holders within the allowed ranges and minimize gas flaring. At the same time it will also calculate the optimal own power generation and purchased power schedules.

The efficient use of the byproduct gases is essentially important for the profitability of steel mill operation because of the high energy volumes and costs involved. The improved efficiency will also reduce carbon emissions, which are traditionally large in the steel industry. Despite the importance and the potential benefits, the reported optimization applications tend to be more like academic feasibility studies while descriptions of actual robust real time multi-period optimization systems of steel mill byproduct gases are still missing (1), (2).

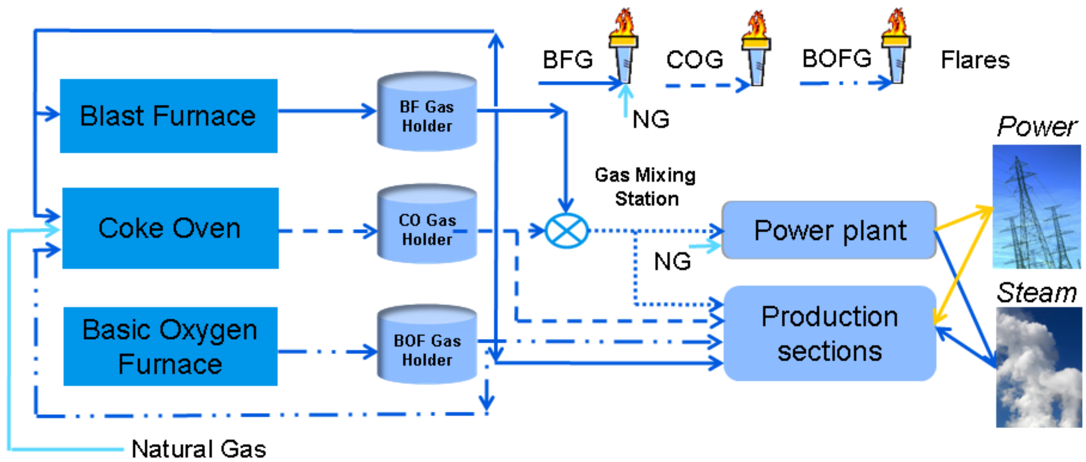

Figure 1. Integrated steel mill energy flows

FEASIBILITY STUDY

ABB has carried out a feasibility study for an integrated steel mill that produces multiple types of high calorific value gases that have to be distributed between multiple consumers. In this case, the gas network consists of five different types of gases with different calorific values as follows:

- Blast Furnace Gas (BFG)
- Coke Oven Gas (COG)
- Basic Oxygen Furnace Gas (BOFG)
- High Pressure Corex Gas (HPCX)
- Low pressure Corex Gas (LPCX)

In addition, there are two Gas Mixing Stations that produce mixed gas using BFG and COG.

Byproduct gases are supplied to 40 consumers, which include in-house as well as external consumers.

Currently, the gases are distributed to various consumers based on heuristic rules derived from operator experience. The procedures may not allow timely handling of uncertainties in the gas generation and demand of various consumers in an optimal manner. This increases the flaring of byproduct gases resulting in loss of energy and money.

The problem is to optimally distribute the above gases among the consumers to meet the demands of all the consumers while minimizing the flaring of gases. While achieving these objectives, the optimal distribution has to respect various types of restrictions related to the gas network configuration due to compressors, gas mixing stations, and the gas combinations that can be supplied to the consumers. In addition, the flow rate limitations in the gas networks and gas holder level rise rate limitations shall be respected.

The gas network configuration restrictions lead to integer type decision variables to select between the possible alternative configurations. In the study the optimization problem was configured as a Mixed Integer Linear Programming (MILP) model which was solved using a commercial solver. The model was tested with data recorded from the steel plant. In order to make the tests more realistic, ± 10% to 15% variations were considered in demand and supply of the gases, respectively. The tested variations simulated disturbance scenarios, which can frequently occur in a steel plant.

For all of the tested cases, the flaring of gases was less than 50% of the current practice at the steel plant. Thus, the proposed optimization solution reduced significant amount of flaring, and Increased energy efficiency. This will finally lead to significant amount of profit, i.e. about 2 - 5 MUSD/year for a steel plant with 8 million tons/year steel production.

ENERGY MANAGEMENT WITH GAS OPTIMIZATION

ABB is currently implementing an Energy Management System (EMS) project that includes real time energy optimization for gas, electrical and steam networks and power plant of an integrated steel mill. The project is being carried out as a joint effort together with the project teams of ABB and the steel mill, and it is now in the commissioning phase.

Process Description

The mill has the capacity to produce up to 5 Million tons of steel per year. The main production sections considered include the sintering plant, coke oven plant, two blast furnaces, steel plant with basic oxygen converters and in ladle vacuum degassing, continuous casters, hot strip mill and multiple finishing lines.

The gas fuels include byproduct gases (COG, BFG and BOFG, also called LDG) and imported Natural Gas (NG). Liquid fuels used at the Power Plant include byproduct tar and naphthalene and imported oil.

The Power Plant produces steam in four steam boilers. The boilers can be fired with the available gas and liquid fuels in various combinations. Boiler efficiencies are different depending on the boiler unit and the fuel used. For some boilers and fuels the efficiency is relatively constant in the allowed operating range, but for others the efficiency depends on the operating point.

The high pressure steam is used to generate electricity in four turbine-generators and to run two turbo-blowers that deliver air to the blast furnaces. Medium or low pressure steam is used for vacuum degassing in the steel plant, heating of buildings, etc.

In addition to the power generated in-house, purchased electricity is supplied from the grid as needed to meet the total mill demand. The time schedule of electricity volumes to be purchased from the day-ahead market shall be forecasted daily for the next day.

Production rates of byproduct gases as well as gas, electrical and steam energy demands of the production sections are based on the mill's production schedule and there is little or no flexibility to change them.

Optimization Model and Goals

The optimization model maximizes the efficiency of using the byproduct gases in the production sections and power plant. To support daily planning and monitoring of operation, the time horizon of the model is up to one week with ½h time steps.

The optimal solution minimizes the total cost under the following conditions:

- Gas holder levels shall be maintained within allowed operating ranges to avoid flaring of gases
- The power plant shall be operated in the most efficient configuration possible within appropriate constraints, i.e.
  - Allocation of gas and liquid fuels to the boilers shall consider boiler efficiencies on each fuel. For some boiler/fuels, the efficiency changes with operating point
  - Boiler startup ramp rates and costs shall be considered
  - The constraints on connecting boilers and turbines into the HP steam networks shall be respected
  - The required operating margins (spinning reserves) of the generation units shall be respected
- The volumes of purchased electricity and own power generation are optimized. The price of purchased electricity may include penalty costs due to forecast errors.

- The model can also be extended to optimize the volumes of sold electricity and byproduct gas, if the technical and contractual opportunities are available to export them.

The total energy cost to be minimized consists of the cost of purchased fuels (NG, oil) and electricity. The optimal solution will also minimize the flaring of gases and maximize the efficiency of steam and power generation and use.

EMS Implementation

The forecasted energy consumption and byproduct gas generation schedules are based on previously recorded correlations between mill production rates and the variables to be forecasted. Medium term production planning data needed for the calculation of the forecasts is entered into the EMS from an interface to the mill's order processing and production planning system. This data may be updated later by production schedules received from short term production planning and tracking systems. Forecasted production rates and interruptions can also be entered and modified by production section operators from EMS user interface.

The optimization model is configured using ABB's Economic Flow Network (EFN) modeling tool. Energy consumers, suppliers, boilers, turbines, gas holders, etc. components and networks with related contracts, prices, costs and constraints can be configured into the model from EMS user interface and maintained without programming. The EFN modeling tool transforms the configured model into an optimization problem that is then solved by a 3rd party MILP Solver.

The input variables to the model include

- current state of production sections and power plant as measured by the instrumentation and control systems
- forecasted schedules of (gas, electrical and steam) energy demand and gas and liquid fuel generation in the production sections

The solution of the problem provides the optimal energy supply schedules for the production sections and the power plant, including schedules of

- supply of fuels to production sections and the boilers
- boiler states and steam generation rates
- steam turbine states and electricity generation rates
- in-house electricity and steam consumption at power plant
- electrical power purchased from the grid.
- NG purchased from the grid
- consumption of liquid fuels
- gas holder levels and flared gas volumes
- fuel tank storage levels

The forecasts are updated from time to time as new production plans are received from the production planning systems and the user interface. The execution of optimization is automatically activated to calculate the new optimal schedules after the changing of the forecasts and other input variables based on specified conditions.

User Interface

The main users of real time optimization are the operators of the production sections and the power plant. Production section operators will update each morning the section's production schedule and validate the forecasted schedules of gas, electrical and steam demand and byproduct gas generation. Each production section has a dedicated user interface display for the entry of the data in Gantt or trend chart from.

Power plant operators supervise and control the operation of the power plant. Each morning they will run the optimization after verifying that the production section forecasts have been properly entered and after updating the power plant inputs needed for the optimization.

The operators shall implement the optimal byproduct gas distribution and power plant operating schedules by controlling their processes and the power plant accordingly. The optimal schedules are presented on the EMS user interface using displays specifically configured for each production section and the power plant. The display will show the optimal schedule as a bar chart diagram in parallel with the corresponding actual schedule that is updated in real time. This will help the operators to detect deviations from the optimal schedule.

Any unplanned changes in the schedules of the production sections or the power plant should be entered into the EMS by the operators. Because the quality of the optimization results is dependent on the accuracy of the optimization input variables, any changes to forecasts should be updated in advance as soon as possible.

Power plant operators have the means to control the optimization to use the available fuels and the power plant resources according to their preferences. For each boiler, the operator can select from a Gantt diagram a time-range and fuel. He can then control the use of the selected fuel in optimization by entering (*use / deny*) below the Gantt line as shown in Figure 2. If no *use / deny* data has been entered, the optimization will calculate the usage. In this way the operator can override the corresponding previous results of the optimization and start a new optimization run that will respect the settings given by the operator. The same technique can also be applied for other optimized variables.

The diagram in Figure 2 below presents actual historical data on the left, and future planned and optimized data on the right. The lower part of the diagram shows the boiler fuel flows as bars and the steam flow as a line.

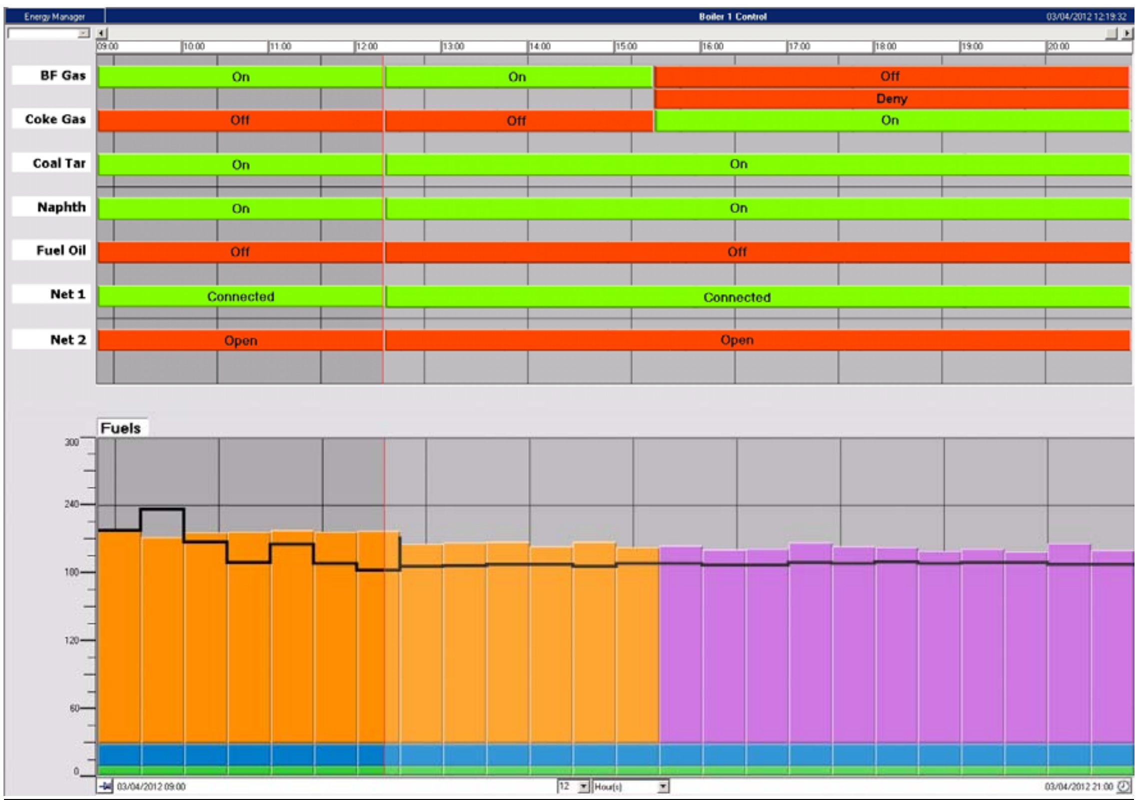

Figure 2. Boiler optimization control display

Monitoring and Targeting dashboards

The benefits of the EMS can be extended by long term Monitoring and Targeting display dashboards to visualize and analyze energy and utility consumption and other energy KPIs. A mil specific set of dashboards can be made available for the total mill and each production section in the same form.

As an example, the Energy Performance Dashboard in Figure 3 presents energy consumption, energy costs, or CO2 emissions with corresponding targets by energy type and over a time range as selected by the user. Additional dashboards are provided for the setting of targets, and analysis and reporting of the energy data.

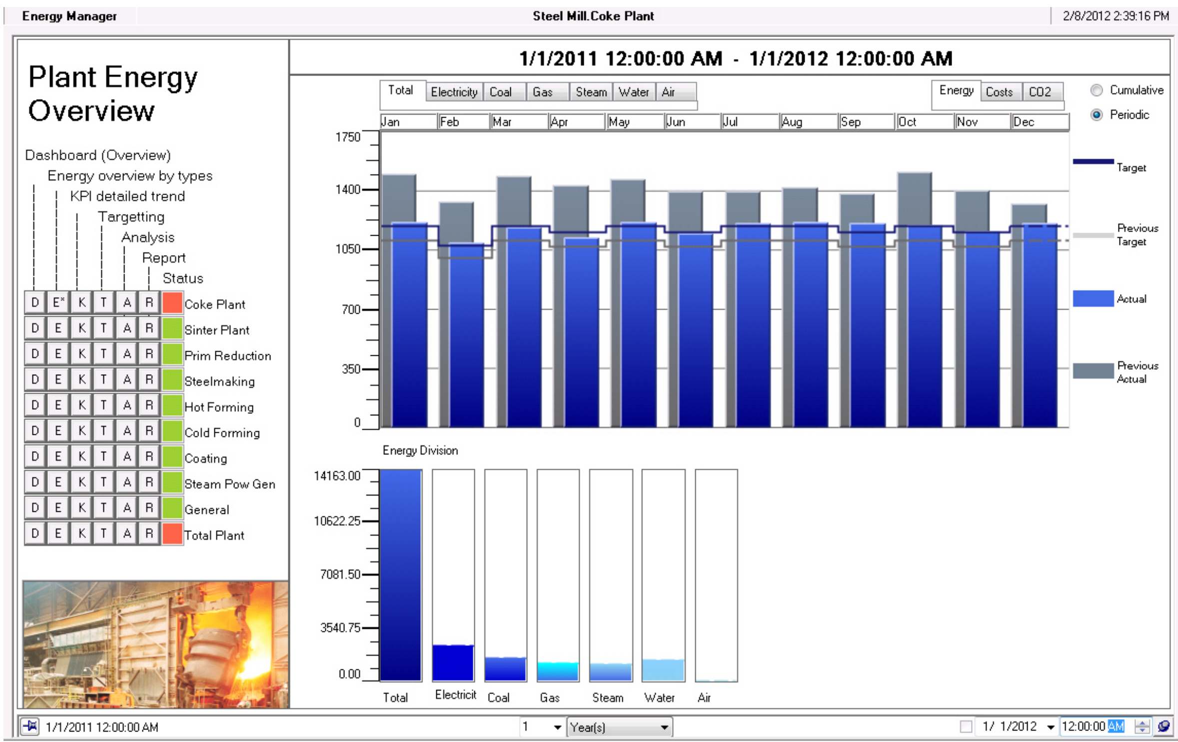

Figure 3. Energy Performance Dashboard

CONCLUSION

The implementation of the system has proceeded to the commissioning stage and as the first step the production section operators are using it to enter the electricity demand forecasts. The accuracies of the forecasts are verified by comparing with measured data.

In the early project phase the emphasis in the optimization model development was on the specification of the requirements in detail to allow model configuring. After configuring, the model is first tested using historical data recorded from the mill.

At the final step the optimization model is integrated with the demand forecasts and validated in various operating situations.

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