Dicing the load

Flexible production saves energy costs

IIRO HARJUNKOSKI, LENNART MERKERT, HUBERT HADERA, ANTTO SHEMEIKKA, DRAGOLJUB GAJIC, LUCA ONOFRI – Many energy-intensive industries such as steel, pulp and paper, and cement face the challenge of how to deal with the effect of increasing and fluctuating energy prices on daily production operations. New collaboration schemes offered to these industries through intelligent and flexible electricity networks (smart grids) significantly reduce total production costs by optimally timing electricity consumption. The main concern is how to make the production process flexible enough that a company can buy electricity when it is cheap – and even sell it back to the grid during peak hours. At perhaps a hundred times the purchase price. ABB has investigated and developed new approaches to this business proposition.

Title picture
Shifting production in energy-intensive industries to times when energy is cheaper can result in significant savings. How can the many variables, constraints and industry-specific aspects be taken into account to produce an optimized model?


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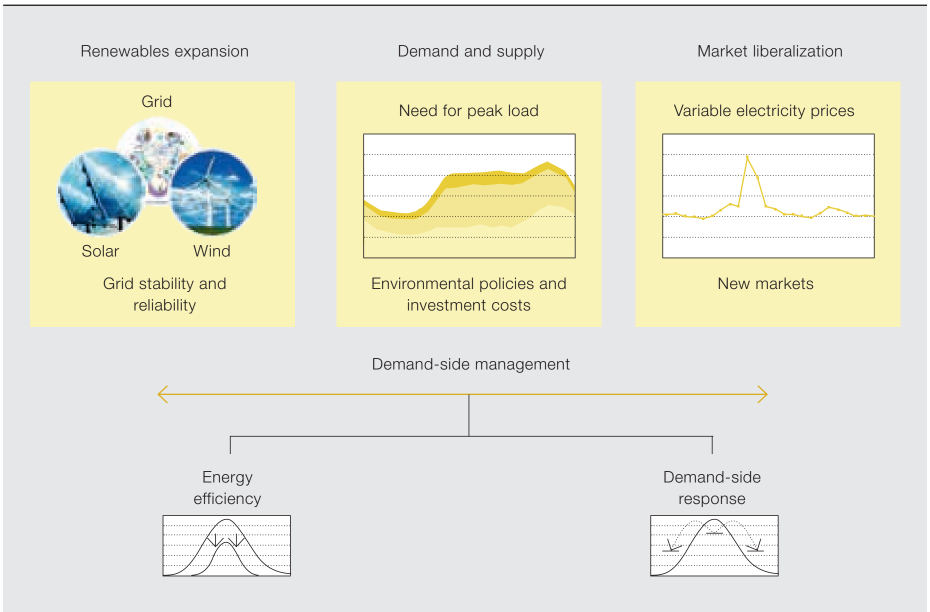
1 Energy demand-side management concept and the motivation for having it



Replacing traditional stable and controllable energy sources with fluctuating renewable sources means energy supply and price can no longer be taken for granted. Because of this, market tools for purchasing and selling electricity have become almost a necessity for large consumers. Since the price of electricity has a direct impact on production cost, large consumers have also started to consider including energy forecasts in their production planning. This concept, coupled with energy efficiency, is called demand-side management.

In contrast to energy efficiency strategies, which aim to produce the same using less energy, demand-side response focuses on profitable time-shifting of the load → 1. In practice, this means that an industrial plant needs to adapt production according to the energy cost situation. If future electricity pricing information is available – and this discussion will assume it is – many processes can take it into account in short-term planning or scheduling.

Energy management solution

ABB already offers a solution for optimizing the energy portfolio for a given production plan: cpmPlus Energy Manager has been available for more than a decade and covers energy conversion (eg, fuel to energy), purchasing from various markets and also some production planning decisions – especially for continuous processes. The solution has been installed by many types of customers – including pulp and paper, metals and mining – as a part of ABB's collaborative production management (CPM) solution and has demonstrated significant benefits.

→ 2 shows the Energy Manager solution for a thermomechanical pulp (TMP) mill, with the production lines displayed in the upper diagram and the fiber storage tank level in the middle diagram. A mathematical optimization is used to simultaneously consider all energy-consuming and energy-producing units together with the option of purchasing from or selling the energy to the grid based on current prices. The electricity consumption of the three TMP lines is shown in the bar graph in the lower part of → 2 and the varying electricity price is indicated by the yellow line.

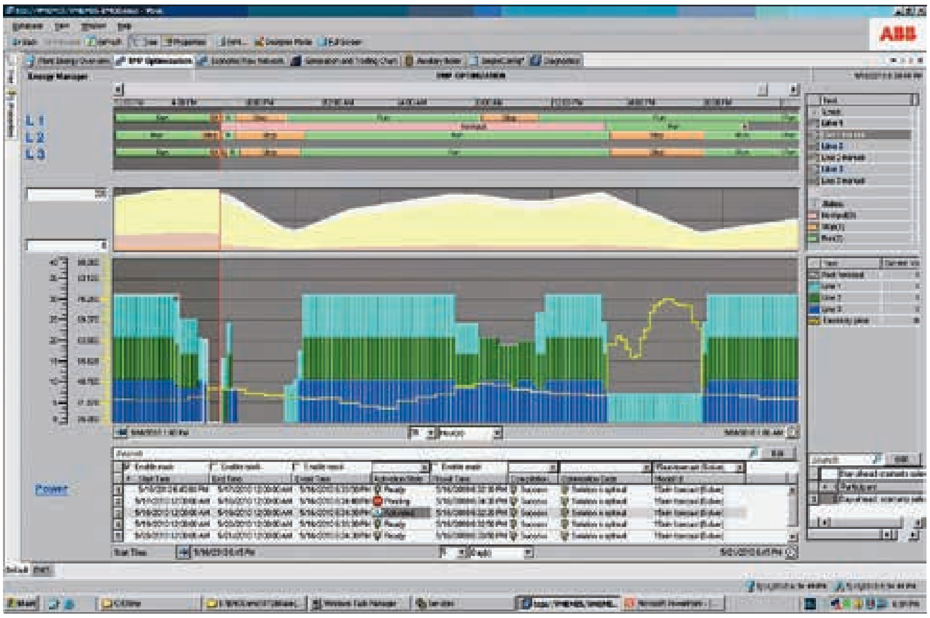
This example illustrates how a CPM solution can collect and connect information from various sources and generate the most cost-efficient production strategies, while also taking into account electricity costs. As the solution also includes other production units, it decides when to run which production line, taking into account, for example, total downstream steam demand, the capacity and cost of alternative steam sources, the production plan of the paper machines, and the minimum and maximum production limits of each refiner line.

Holistic optimization

The TMP example assumes that there exists at least a partly prespecified production schedule → 3a. The scientific challenge arises in simultaneously optimizing the production schedule and the electricity purchase strategy → 3b. The main idea is to optimally schedule production while considering aspects from the control, scheduling and supply chain layers. Mixed-integer linear programming (MILP) techniques represent a very promising way to arrive at holistic optimization solutions to problems like this that have partly competing targets. MILP solvers have improved significantly and

In contrast to energy efficiency strategies, which aim to produce the same using less energy, demand-side response focuses on profitable shifting of the load in time.

2 Energy management solution for a TMP mill. All lines are stopped during the highest electricity price peak.



The scientific challenge arises in simultaneously optimizing the production schedule and the electricity purchase strategy.

can now solve problems that are several magnitudes larger than those of a decade ago.

The problem of simultaneously optimizing energy management aspects and production planning needs has still not been completely solved and researchers are currently trying to find ways to handle this in realistic production environments. Nevertheless, ABB has collaborated with a steel company on this topic to come up with some feasible concepts that are currently being tested live in production.

Scheduling the steel-making process

Scheduling production in a steel melt shop is not easy, partly due to the extreme processing and material temperatures. For example, each production delay leads to cooling and later a reheating need. Therefore, there is a strong demand in the industry for automatic production schedule optimization. Attention must also be paid to other implementation aspects such as enabling different melt shop configurations and product portfolios; appropriate graphical user interfaces (GUIs); integration with other IT systems, eg, enterprise resource planning (ERP), energy management systems and process control systems. Without all these aspects, even the most sophisticated scheduling optimization model can never be deployed in a real production environment.

Industrial demand-side management

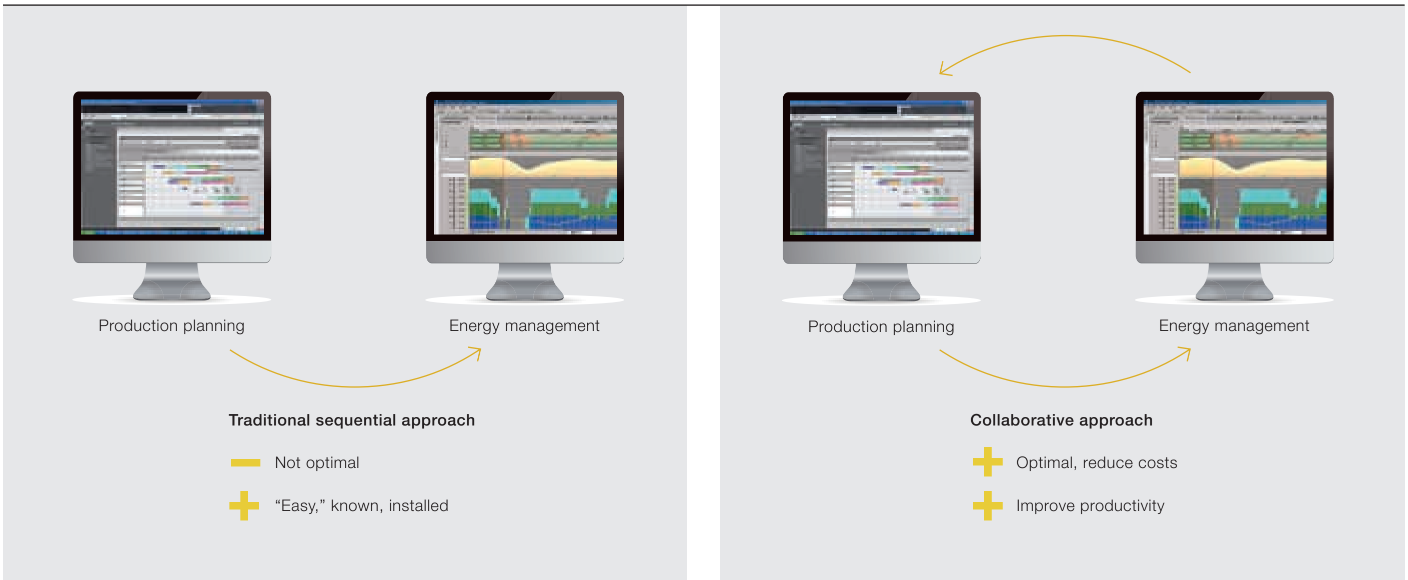
ABB developed new concepts allowing industrial demand-side management (iDSM) by automatic optimization of the production schedule against the electricity costs. The first step toward the iDSM solution was to investigate the use of monolithic models for the integration schemes shown on the far right in → 3.

→ 4 depicts the idea in which an additional time grid is added to the original scheduling formulation in order to check the electricity consumption in each of the slots formed. The electricity provider or the electricity market defines the energy price for each of these time slots (15 to 60 min). Theoretically, this holistic-model-based optimization may lead to a so-called global optimum, ie, the best possible solution with respect to both the production and electricity costs. However, holistic models are very often complicated or impossible to solve within a reasonable time, so some refinement is required.

Refining the models

In production processes that require multiple production steps, such as batch-oriented steel manufacturing, typically not all equipment is continuously occupied. This allows flexibility to adapt production according to energy management needs. Multistage production processes also usually have buffers to store raw material, and intermediate and final products – for limited periods of time. In

3 Collaboration between energy management and production planning



3a Here, at least a partly prespecified production schedule is assumed.

3b Here, the production schedule and the electricity purchase strategy are simultaneously or iteratively optimized.

MILP solvers have improved significantly and can now solve problems that are several magnitudes larger than those overcome a few decades ago.

the melt shop process, for example, intermediate products are very hot so inadequate coordination of subsequent production stages causes energy loss through cooling. Another constraint is that large electricity consumers commonly have to commit their forecasted load pattern upfront and suffer financial penalties for deviations from it.

In the work done by ABB, the continuous-time (exact) melt-shop scheduling model has been refined to take into account both the electricity price as well as deviations from a committed load curve. The benefit of this approach is that the energy considerations can be included in the original scheduling model by adding new decision variables to map the electricity consumption for each grid-defined time slot. This results in feasible solutions with clear energy savings potential. However, this basic approach is not efficient for more complex instances. Therefore, various alternative approaches have also been looked at including other modeling philosophies – eg, resource-task network – as well as decomposition algorithms.

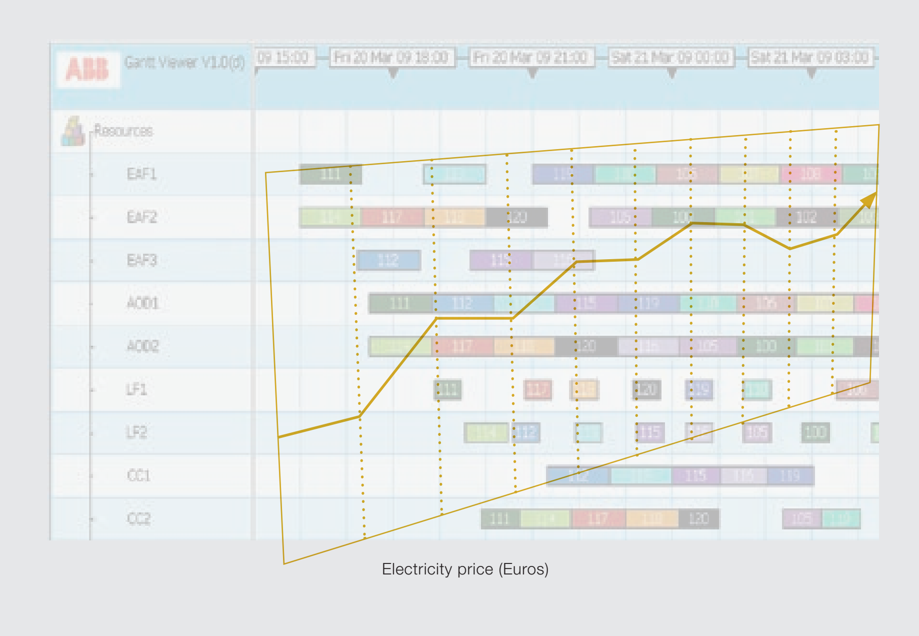
ABB has collaborated with a steel company to test a number of approaches and come up with some feasible concepts that are currently being tested live in production.

Energy pricing and usage scenarios

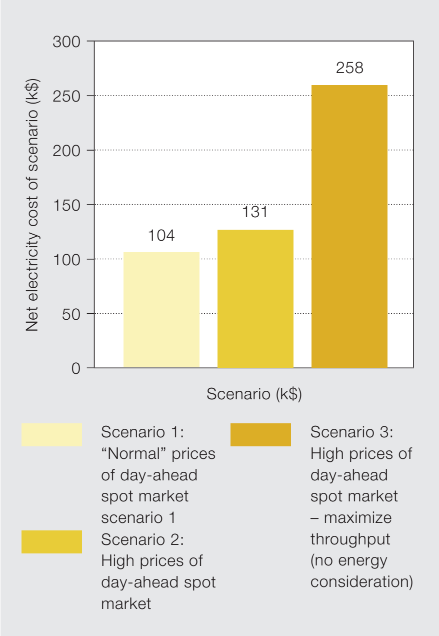
Based on realistic data, a hypothetical case study has been carried out to investigate how strongly three different energy tariff scenarios might influence the energy bill for a typical 24-hour scheduling problem → 5. The scenarios are each assumed to buy a fixed amount of electricity at a known rate using a base load contract. The total energy bill can be reduced by reselling any surplus electricity. The committed load aspect is also taken into consideration.

The first scenario represents a day with "normal" electricity prices in the volatile day-ahead market. When the scheduling driven by energy price is employed, the net electricity cost is around $110,000. The second scenario uses weather-driven prices, which result in an additional cost of $27,000. The third scenario ignores energy price considerations, ie, only production throughput is optimized

4 The grid delineating the electricity price time slots



5 Total electricity cost for various energy prices and optimization strategies



– resulting in a cost double that of the second scenario. This demonstrates how much the plant could potentially save by collaborative scheduling and energy optimization on a day with extreme prices.

In this case study, energy-driven scheduling contributes to significant reductions of the electricity bill. However, comparison of the schedules of scenarios two and three clearly shows that the energy-driven schedule tries to avoid extreme prices of the peak hours (marked in red and orange in → 6) at the expense of extending the overall makespan (the total time needed for production) → 6. Some of the production operations are delayed – perhaps incurring reheating costs. In the study, the cost of thermal losses has not been included in the savings calculation. However, with realistic cooling models it is certainly possible to account for potential costs that can be associated with production delays.

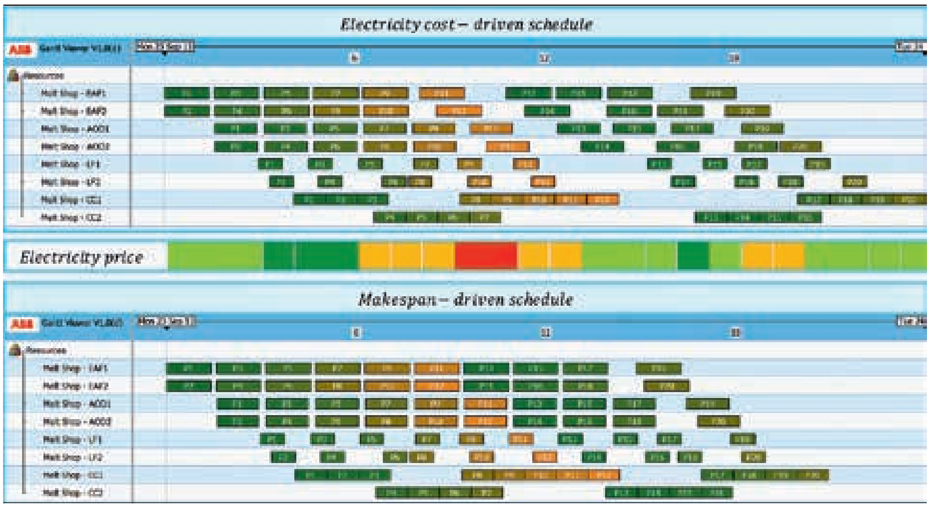
Scheduling solution

A new ABB production scheduling system based on MILP technology was deployed in a very complex melt shop belonging to Acciai Speciali Terni SpA, a member of ThyssenKrupp and one of the world's leading producers of stainless steel flat products. With the new system in place, the production scheduler is able to automatically and optimally create a new schedule, or manually update an existing one, for up to seven days of production within just a few minutes. The system is flexible enough to support different melt shop configurations, as well as to include all other information necessary – such as processing, transportation, setup and cleanup times – to generate a feasible production schedule. It also takes into account maintenance plans, the current status of the melt shop and availability of different equipment, due dates, penalties for lateness and violation of holdup times between stages in the process, etc. In addition, the steel plant created a Web-based GUI that allows the user to flexibly select what to optimize and schedule → 7. The list on the left in → 7 shows production steps or units, such as the electric arc furnace (FEA) and ladle furnaces (ASEA). For each unit, there are two rows. The "monitoraggio," row is related to monitoring and shows the current status of the unit and what really has happened there. The "programma" row shows what has been planned/scheduled in each unit. Thus, the GUI also enables other departments to initiate appropriate actions in order to minimize potential losses and production delays – for example, reschedule or postpone production slightly due to a high electricity price. The new scheduling system is not only linked to other internal IT systems such as ERP and process control, but also to the external day-ahead electricity market, in order to dynamically cater for volatile electricity prices.

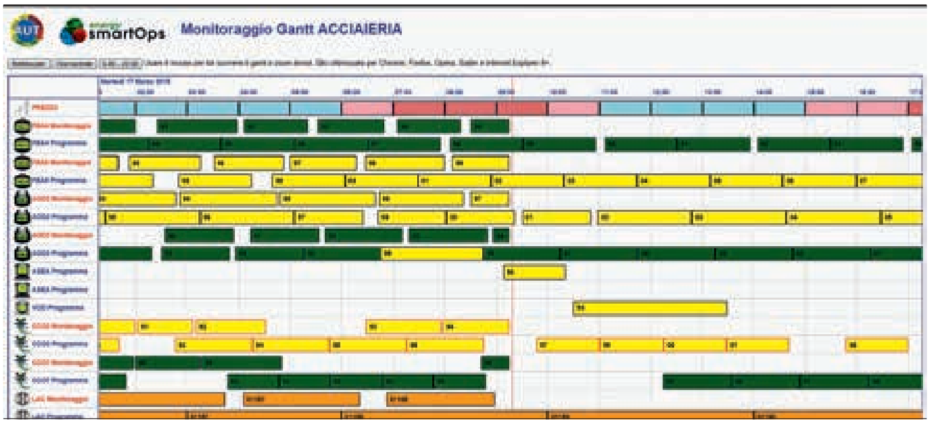
The continuous-time melt-shop scheduling model has been refined to take into account both the electricity price as well as deviations from a committed load curve.

The production scheduler is able to automatically and optimally create a new schedule, or manually update an existing one, for up to seven days of production within just a few minutes.

6 Comparison of schedules driven by energy cost and makespan cost



7 Web-based GUI of the new production scheduling system. Prices can change by the hour.



Furthermore, in cooperation with ABB, the steel plant has also integrated into the new scheduling system an advanced solution for optimization of the production schedule, taking into account electricity prices as well. This advanced solution enables the plant to optimize its electricity costs and makespan and thus play a more active role in demand-side response programs and support grid reliability and safety.

It has been shown that the implementation has improved the coordination between different production stages in the melt shop and thus decreased the hold-up times between these, reducing energy consumption. The system has also been recognized as a very useful tool for running various simulations and what-if analyses. The benefits are estimated to be in the range of 2 to 5 percent – a considerable saving given the large energy budgets involved.

Flexibility is key

The complexity of production scheduling is increasing in industries outside of steelmaking too, mainly due to smaller and more customized orders. Production plants now have to be agile and flexible to respond to short-term changes. These industries also face the complexity arising from variable, but potentially more affordable, electricity pricing on an hourly basis in the day-ahead market. Consequently, combined energy and production planning processes must always be well integrated with real-time data. Having a full offering of process and grid automation, ABB has the tools to realize a proper matching of supply and demand using internal buffers in the process and production load shifting for a wide range of industries.

Iiro Harjunkoski
Lennart Merkert
Hubert Hadera (formerly ABB)
ABB Corporate Research
Ladenburg, Germany
iiro.harjunkoski@de.abb.com
lennart.merkert@de.abb.com

Antto Shemeikka
ABB Process Automation, Process Industries
Helsinki, Finland
antto.shemeikka@fi.abb.com

Dragoljub Gajic
Luca Onofri
ThyssenKrupp AG, Acciai Speciali Terni SpA
Terni, Italy