Applications of Virtual Power Pools – Demand Response at Industrial Sites

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This paper discusses the combination of virtual power pools (joint control of power generation, power consumption and storage units) with demand response (capability of providing flexibility with regard to electrical energy consumption at industrial sites). We report the state of the art, show new opportunities through new business models, describe the necessary underlying technical concepts and analyze the potential of energy cost reductions. The same models and concepts are applicable to commercial sites or residential areas.

1 Introduction

The power industry is undergoing a rapid and profound change, resulting in new business models, which allow industrial sites to profit from providing flexibility to the power market using demand response. Industrial sites typically either comprise on-site power generation units or regulated connections to the power grid or both. Moreover, the site's energy consumers often are a mixture of critical industrial processes as well as other non-critical components. In addition, storage capability often is available.

From an industrial point of view, there are generally two ways to benefit from the demand response: First, an active site can dynamically optimize the power supply depending on the price and availability of energy. Second, a passive site can provide its flexibility on demand to a commercial partner.

Our main contribution is to show how to combine production planning, energy management and energy trading in order to reduce the energy cost and increase the financial benefit from providing flexibility to the grid operator. All this, without changing the production goals or moving production deadlines. Additionally, we present successful real-world demand response applications, where industrial site operators could increase the productivity and the financial benefits using mathematical optimization for demand response.

Motivation and market driver for virtual power pools

Numerous successful applications of joint control of decentralized power generation units, energy storage devices and controllable consumption units have conquered the energy market and disrupted the business cases of classical energy providers and utilities. Pooling small and medium sized assets and devices to a virtual power pool (virtual power plant, VPP) allows the operator to optimize the production and consumption inside the power pool and obtain better prices on the energy markets. Comprehensive information flow from the field devices to the energy management system facilitates fast decision making, which again is used to optimize operation of the assets and bidding on the energy market, ideally using automated trading (see Figure 1). The VPP-operator requires a control system that allows him to run and manage his power pool operationally and commercially optimal. The publication [1] describes how to set up a virtual power pool and adapting it for the underlying business model.

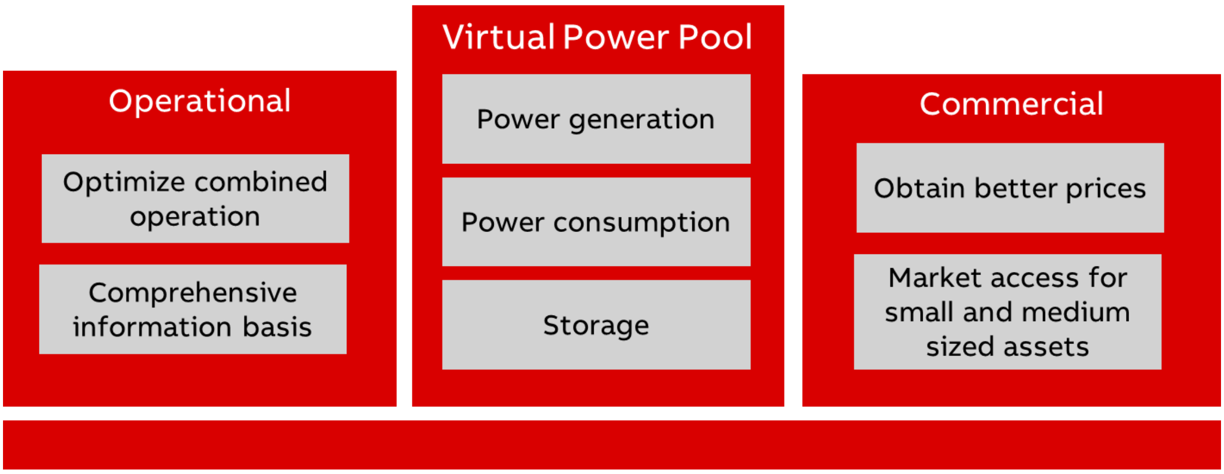

Figure 1: Operational and commercial optimization of a virtual power pool

Motivation and market driver for demand response

Demand response schemes are well-established tools that allow energy providers to shed the load of energy intensive industries in case of emergency. There is no generally accepted single definition of demand response and the differentiation with related notions like demand-side management or demand-side participation often is unclear. In this work, we use the notion of demand response very broad: Energy consumers react to price or availability of energy and dynamically increase or decrease their power consumption accordingly. The energy demand is not solely driving the energy production, but the demand is aligned to the availability and price of energy.

Apply demand response schemes to virtual power pools

The advantages of virtual power pools and demand response can be combined to exploit the potential of new business models. The same models and concepts are applicable to commercial sites or residential areas. Generally, combining production planning, energy management and energy trading reduces the energy cost and increases the financial benefit from providing flexibility to the grid operator. All this, without changing the production goals or moving production deadlines.

This paper is structured as follows: We start with an introduction and report the state of the art in Chapter 1 and 2. We then show new opportunities through new business models and describe the necessary underlying technical concepts in Chapter 3 and 4. Afterwards we give real-world examples for the discussed approaches in Chapter 5. We close with a conclusion and outlook in Chapter 6.

2 State of the art

In many industries, demand response and energy management is not a new technology. Especially in energy intensive industries, energy management has been a focus already for many years.

Traditionally, the key application for energy management is an energy monitoring system allowing a detailed (real-time) energy consumption overview. Having such a monitoring system allows to identify inefficient equipment as well as inefficient modes of operation and to plan and execute suitable energy efficiency actions.

Load forecasting is a more advanced means which allows to reduce energy cost by more accurate procurement strategies. Advanced energy management solutions usually are having a load forecasting module based on consumption history, load profiles and/or production plans.

Having on site generation a generation optimization module is economically interesting especially for large industrial plants. Such modules, running an optimal unit commitment problem, are already commercially available (e.g. ABB OPTIMAX® Powerfit) and allow to ensure energy provision at minimal cost.

Especially the large energy intensive industries already today participate in demand response markets. In particular, direct load control by grid operators in the framework of tertiary frequency reserve is quite common. This is offering an additional revenue stream for non-critical consumers in energy intensive industry. The most advanced industrial sites concerning energy management are even changing their business model such that provision of energy services is core in their operations strategy. For example, an US aluminum smelter is providing primary frequency reserve and hence adapting his production to power grid needs in a range of seconds. [13]

In the academic world there have been many studies and proposals how to use electric vehicle charging for demand response actions (among many others [16][17][18][19]). However real world applications of these technologies and approaches are still quite rare, as the market for electric vehicles has not grown to an important share yet.

In contrast, battery control is by now widely used for demand response applications, e.g. the German distribution system operator EWE Netze and ABB have installed a decentralized battery storage system to absorb surplus PV generation and return energy in the evening hours. Additionally, the battery storage is used for intra-day trading during night times [6]. Another example is a battery storage system by WEMAG in Schwerin, where the newly installed capacity of 5 MW / 5 MWh is utilized for primary frequency control (see [7] and [8]).

A comprehensive overview on the current state of the art on demand response and load management algorithms can be found in [6].

The situation concerning market penetration and technology choice is very heterogeneous: Both strongly depend on the corresponding region, energy market regulator and industry. An overview for Europe can be found in [4], an overview for the U.S. in [5].

3 Disruptive Business Models and Demand Response Schemes

There are various existing business models that deal with offering industrial flexibility to the power system. Possibly involved parties are utilities, transmission system operators (TSOs), industrial enterprises, virtual power pool operators and aggregators. The industrial flexibility could stem from company-owned generation units, energy storage, production storage, production plan rescheduling, production stop and load shedding. Flexibility can be exploited on timescales ranging from milliseconds to days.

Industrial sites, commercial sites or office buildings can offer their flexibility directly to grid operators or aggregators through bilateral contracts or by participating in auctions. Enterprises with large-scale consumption or production can also directly participate in intraday-, day-ahead or balancing-markets. One common point for all those options is, that different demand response schemes are considered separate from each other, leaving commercial potential untapped.

For a virtual power pool operator, the business model is based on the energy market that is targeted. It can range from providing balancing power to the transmission system operator (TSO) to trading expected surplus or deficient energy on the spot markets [1].

Figure 2 shows the interaction between the VPP operator or energy provider and the industrial enterprise. The VPP operator is entrusted to monetize the provided flexibility. This can either be done by trading surplus or deficient energy on the energy markets or by using the flexibility in its power pool to compensate for times with high or low power availability.

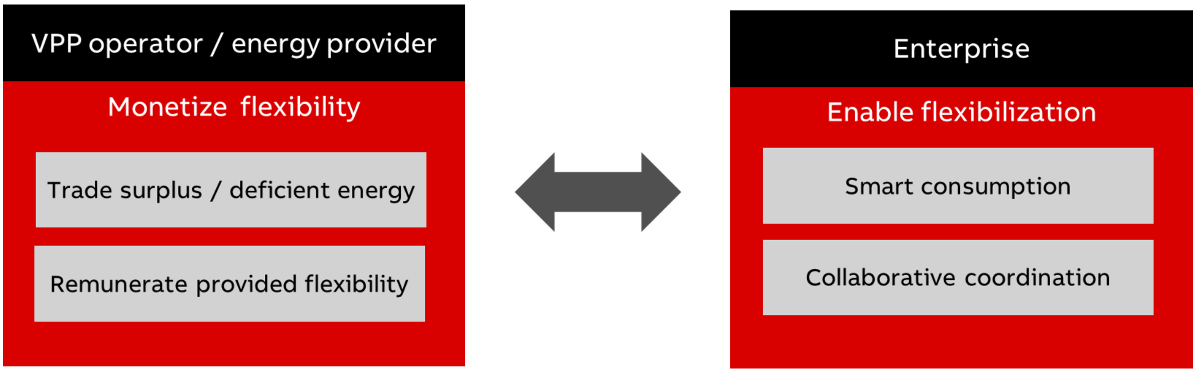

Figure 2: Interaction between VPP operator or energy provider and the industrial enterprise

The technical task for enterprises providing demand response is to dynamically optimize the own power consumption based on price signals or availability indicators and to control the power consumption through coordination of power production units and processing lines. This either can be done by so-called smart consumption or by collaborative coordination between energy and production management.

The notion of smart consumption describes the energy supply optimization when intelligently exploiting the supply contract with the energy provider. This means that the assets on sites (on-site power production, processing lines, non-critical consumers, storage devices) are smartly balanced against each other and the grid connection. The goal hereby is to reduce supply from the grid, reduce peaks (peak shaving) and especially to coordinate peak, load and production management in order to minimize the energy cost or maximize the profit from the energy supplier (see Figure 3).

Collaborative coordination is the automated information exchange between production and energy management. In Section 5, a successful implementation of a collaborative coordination scheme is presented.

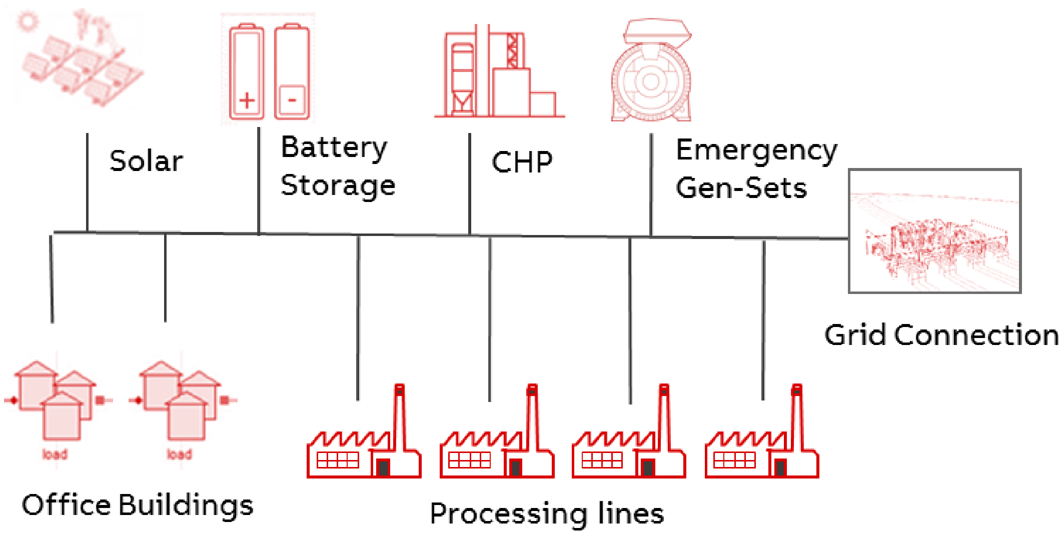

Figure 3: A typical mix at an industrial site with on-site power generation units, storage capabilities, energy consuming office buildings and critical processing lines as well as a regulated grid connection.

Demand Response Schemes

In the past decades, many demand response schemes have been established to formalize the interaction between the flexibility-offering and the flexibility-buying party. On overview can be found in Figure 4.

Price-based schemes give incentives to change the energy consumption profiles by letting the price-per-energy depend on the actual consumption profile. Examples are time-of-use pricing (such as peak/off-peak pricing), critical peak pricing (cost per energy depends on the maximum amount of energy used during a short time-scale) and real-time pricing (price of energy dynamically changes with the spot market price).

In contrast to that, incentive-based schemes allow for a more direct control of the flexibility through the flexibility buyer. Examples are direct control (through the grip operator, based on a bilateral contract), interruptible/curtailable programs, demand bidding, emergency demand response, capacity markets (split into a capacity fee and additional payments when being called) and ancillary services.

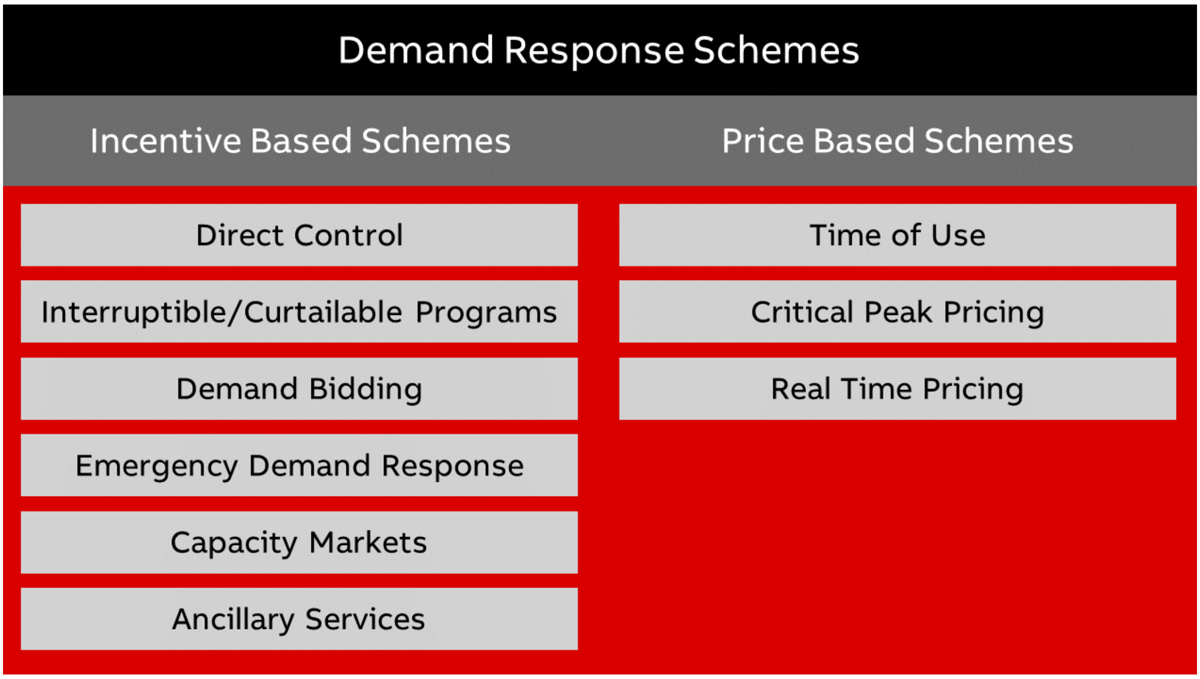

Figure 4: Demand response schemes based on [9].

Combining all the existing building blocks, a new and refined business model emerges: By integrating smart collaboration of production planning, energy management and energy trading, many revenue streams are optimized simultaneously, leading to a better commercial outcome for industrial enterprises. Details on how to do so technically will be given in the next section.

4 Smart collaboration of production planning, energy management and energy trading

The targeted customer segments are industrial enterprises or companies with multiple site locations that have controllable power or thermal generation, controllable power or thermal consumption units and storage options.
In this chapter, we illustrate the concepts to minimize energy cost and maximize revenues using smart collaboration of production planning, energy management and energy trading.
The applications can be divided into activities within one site and enterprise wide activities across all sites, see Figure 5.

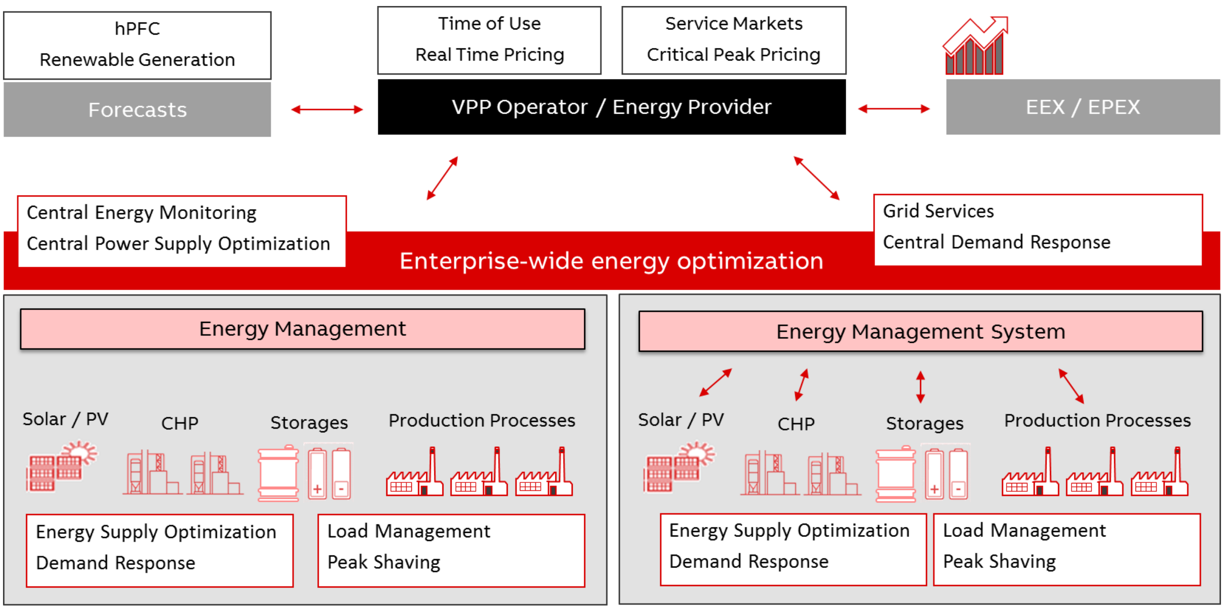

Figure 5: Concepts to minimize energy cost and maximize revenues within one site and across all sites.

Energy supply optimization and Demand Response

Energy supply optimization is the optimal balance between on-site power production, processing lines, non-critical consumer, storage devices and the grid connection. The goal is to reduce supply from the grid, reduce the peaks within the site (peak shaving) through coordination of production management and energy management and to implement automation systems to react on external calls for balancing power or demand response.

On-site power production can either be conventional power plants for providing power, heat and steam or renewable generation from solar, CHPs, power-2-heat. The processing lines with their load curves are critical processes and traditionally determine the energy demand. This paradigm is changed for demand response and energy supply optimization can be achieved interfacing production management with the energy management. Additionally, there are non-critical consumers like A/C or processing lines that are not on the critical path. Storage devices can consist of electrical or thermal storages as well as stores, warehouses and tanks.

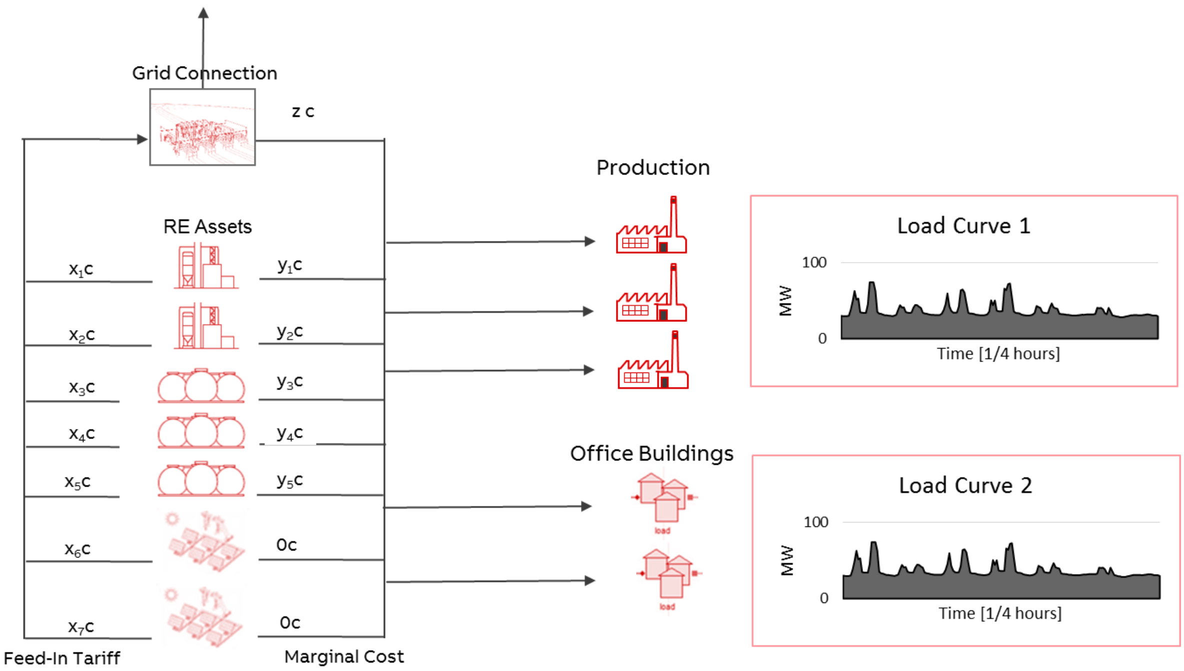

Figure 6: Energy supply optimization is the optimal balance between on-site power production, processing lines, non-critical consumer, storage devices and the grid connection

Finally, the grid connection determines the maximal permitted power supply. The renewable power generation units have marginal cost for operation and can have fixed feed-in tariffs. The cost for supplying energy from the energy provider via the grid connection is defined in the energy supply contract. The energy supply cost can be minimized through an optimal usage of the owned renewable units. Additional revenues can be acquired by providing grid services like balancing power or applying one of the demand response schemes described in Chapter 3.

Load Management and Peak Shaving

Energy consumption can be influenced in several different ways. Most known is the concept of energy efficiency. Here means to reduce the overall energy consumption are taken. For Example, conventional lighting is replaced with LEDs or fixed speed pumps followed by a valve are replaced by variable speed drives. Energy efficiency is a direct way to reduce energy consumption and cost.

Load shedding and load shifting are indirect ways to influence energy cost. It is not in focus to reduce energy consumption for these concepts.

Load shedding is a means to reduce instantly energy consumption by disconnection of non-critical loads. External as well as internal triggers for shedding a load are possible. An external trigger for load shedding can e.g. be the call of secondary or tertiary frequency reserve by the grid operator. An internal trigger for load shedding can e.g. be an algorithm for peak shaving that reduces peak load at high-energy consumption to avoid exceeding a maximum consumption within a billing period. The incentives for load shedding can be a compensation, the reduction of e.g. grid fees or stable operations of islanded power grids.

In comparison, load shifting is usually planned ahead. Here the energy consumption is influenced such that more energy is consumed at cheap times, while less energy is consumed at high price times. The goal of load shifting is to adapt the energy consumption profile to available renewable energy, to reduce variations within the consumption profile or to adapt the consumption profile to varying energy prices.

Collaborative production and energy management

A huge potential for energy cost minimization can be activated by a collaborative approach between the production management and the energy management. In general, the production management determines a production schedule that is handed over to the energy management. The energy management department is responsible for fulfilling the requirements of the production in the most cost efficient way. However, giving the production management insight to the peak and low price times of the energy market allows the production management system to align the production accordingly, without jeopardizing the quality, speed and deadlines of the production plan. An example of energy cost reduction by 5-10% in a steel mill is given in Section 5.

Enterprise wide energy optimization across multiple sites

The full potential of the demand response applications can be achieved when combining the flexibilities enterprise wide across all sites of a company.

The first step is to implement a central energy monitoring to ensure a comprehensive information flow from the field level at every site to the central energy management system. The central energy monitoring system facilitates the contractual position with the energy provider and allows for a better valuation of the energy contracts. Additionally, the single sites can be benchmarked against each other to identify energy efficiency and cost reduction potentials.

The comprehensive information basis uncovers the joint flexibility options and potentials across all sites. This can be used for central demand response with the energy provider or the VPP operator. Joint flexibilities from all sites can be used for providing grid services such as balancing power. The value of the contracted power is not only increased by the amount but by the additional security in case of balancing power calls that can be distributed among any of the connected sites. Additionally, demand response calls from the energy provider or VPP operator can be allocated to the single sites according to the current situation at the sites. In this way, the enterprise itself determines the site and the asset contributing to the demand response call.

Mathematical optimization models for energy optimization

Breaking down the business models to the technical execution leads to three fundamental mathematical optimization models that can be applied. Day-ahead optimization is used to generate the optimal unit commitment and the schedules of all assets. Updates on the forecasted prices on the energy markets and deviation from the expected renewable generation are processed in the Intra-day optimization. Finally, a mathematical model is employed in real-time in order to optimally distribute the set points to the individual assets. System limitations, disruptions and deviation from the latest schedule are registered online and are directly incorporated into the control system.

Examples for mathematical models optimizing the operation of virtual power plants are described in [10] and [11]. Whereas applications of mathematical optimization for demand response can be found in [12]. A mathematical model is employed for optimizing the profit when bidding on the energy markets by [14]. Finally, a two-stage approach for the long term unit-commitment problem with hydro and thermal storage constraints is described in [15]. A comprehensive overview on scheduling and optimization approaches for energy optimization at industrial sites is given in [2].

5 Real-world examples

Especially energy intensive industries are suitable candidates for load management. They are interesting as having a high energy cost already small energy savings allow major cost savings. Additionally the level of automation in industrial plants is high. Hence, large loads can be operated and controlled without major investments in communication and automation infrastructure. Adding smart algorithms and optimization solutions allow tapping the potential of load management.

If energy intensive process steps do not run continuously throughout the day and those process steps are coupled to (intermediate) storage, they can be used for load management applications. Many energy intensive industries like cement, metals and pulp and paper contain such processes where load management can be of significant economic impact.

In cement and pulp and paper industry the production process consists of different production steps having intermediate storages. For cement production, the crushers are the major electricity consumers. Typically they are typically followed by some storage and are not operated 24/7 (see [20]). In pulp and paper industry the thermo mechanical pulping is a major energy consumer. Here electric pulp refiners are splitting up wood fibers in order to produce pulp. This process step is usually followed by a pulp tank, which feeds the paper machine. As cement crushers and pulp refiners are usually followed by a storage the offer some flexibility in production. This flexibility can be used to adapt the production schedule to load management needs.

The major energy consumer in a melt shop for electric steel production is the electric arc furnace (EAF). The melt shop is operate as a batch production process. Smart production planning algorithms allow to reduce energy consumption at high cost times. In Figure 7, the results of such a smart production planning algorithm are shown. As major energy consumers the electric arc furnaces are stopped during high cost times (indicated in red). Even though there is no direct storage on site, an intelligent scheduling of the batch production process allows some flexibility that enables load management.

Using an iterative and generic approach for the integration of production planning and energy management it has been shown using real world plant data from steel and paper industry that significant energy cost savings are possible (5-10%). The approach is not industry specific and is flexible such that it can be integrated into existing energy management and production planning environments. Currently a test in pilot plants is ongoing (see [3]).

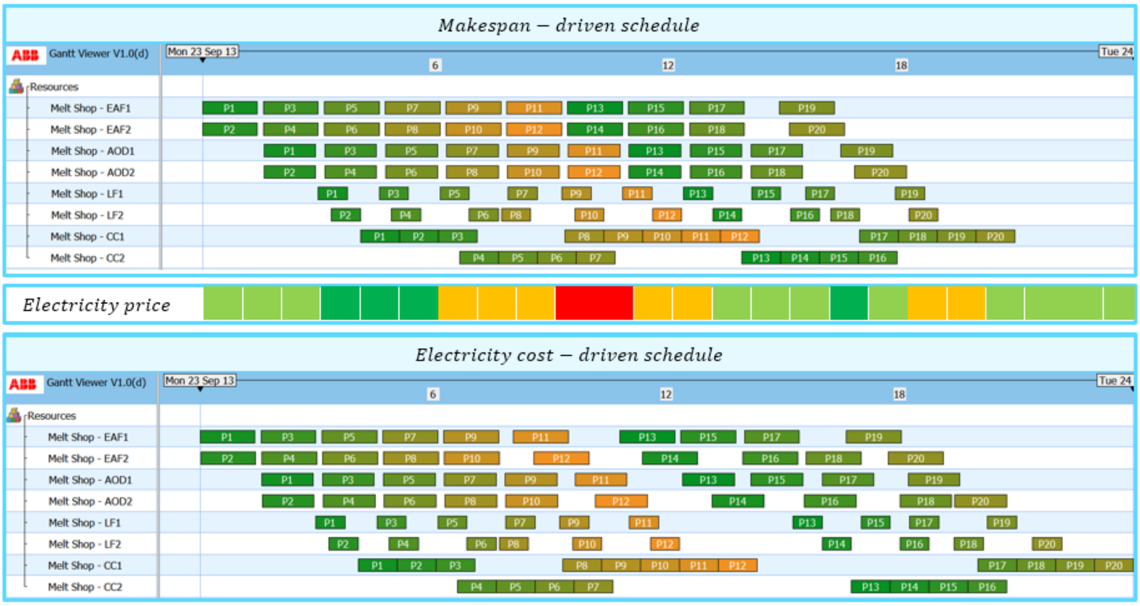

Figure 7: Makespan driven (top) and energy cost driven (bottom) for an electric steel plant. Electricity price is indicated in middle row (green: low; red: high)[3]

6 Conclusion and Outlook

In this work, we showed that demand response applications can be integrated into virtual power pools. Especially in the power industry, disruptive business models are emerging, where industrial sites profit from providing the flexibility of industrial processes to the power market using demand response. Industrial sites normally have own power generation units or regulated connections to the power grid or both. Moreover, they have critical industrial processes that consume energy as well as other non-critical processes and energy consumers. In addition, storage capabilities are often available. Generally, there are two ways to benefit from the demand response from the industrial point of view. First, an active site can dynamically optimize the power supply depending on the price and availability of energy. Second, a passive site can provide flexibility on demand of a power supplier or aggregator. Additionally, combining production planning, energy management and energy trading reduces the energy cost and increases the financial benefit from providing flexibility to the grid operator. All this, without changing the production goals or moving production deadlines

Demand Response is an essential component to benefit from the changing energy markets and to contribute to a sustainable power generation in the 21st century.

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