

Systematic Approach for Energy-Supply-Orientated Production Planning

F. Keller, G. Reinhart

Abstract—The efficient and economic allocation of resources is one main goal in the field of production planning and control. Nowadays, a new variable gains in importance throughout the planning process: Energy. Energy-efficiency has already been widely discussed in literature, but with a strong focus on reducing the overall amount of energy used in production. This paper provides a brief systematic approach, how energy-supply-orientation can be used for an energy-cost-efficient production planning and thus combining the idea of energy-efficiency and energy-flexibility.

Keywords—Production planning and control, energy, efficiency, flexibility.

I. INTRODUCTION

ENERGY awareness and efficiency has become a crucial success factor in production over the last decades. In the past, energy used to represent a cheap and at all times available commodity. It has hardly been considered in production planning compared to other production factors, particularly work force, machine capacity and material [1]. However, especially electrical energy has more and more developed from an unlimited resource to an indispensable production factor.

Today, the importance of electricity has changed. One of the reasons for this development is the steadily increasing worldwide demand and thus rising energy costs for industrial facilities [2]. Another reason is a lack of a guaranteed and stable power supply at all times during a production period [3]. Besides the known limitations of fossil fuels as a conventional source for power generation, the roots of rising energy costs and uncertain availability are manifold. In Germany for example, investments in alternative energies, supply infrastructure and grid stability are main drivers among others and result in annually peaking utility bills for the industrial sector [4]. In addition, the customer perception towards “green companies” has gained importance [5], [6]. Therefore, factories aim to achieve an efficient use of resources and to minimize the environmental impact in terms of their operations [7] within the boundaries of an economically feasible solution.

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Other developments regarding the energy supply of a factory can be observed on the energy markets as well as on the on-site generation. Since the political decision in 2010, the costs of electrical energy have been rising continuously, as Germany is shifting its public power supply towards renewable energy sources [8]. Especially the industrial sector in Germany, which consumes approximately 42% of the generated power [9], is facing competitive disadvantages as the price has risen by the factor 2.5 within the past 15 years. Fig. 1 illustrates the current power cost development for industrial consumers in Germany. Particularly after the decision of the German government to foster renewable energies, the prices kept rising. In fact, costs for energy generation dropped significantly, but taxes and surcharges over-compensated this advantage. The reason is that high efforts are being put into the power grid because of the naturally occurring fluctuation of renewable energy provision [10].

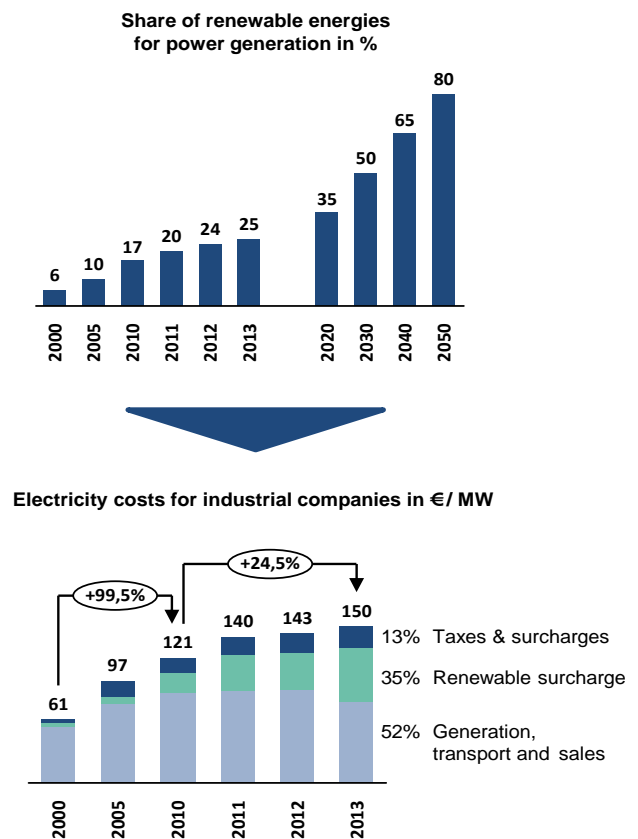


Fig. 1 Development of renewables and electricity costs

In order to face the challenges of the power grid, utility companies have started to design new energy contracts that encourage production sites to adapt their energy consumption [11]. Therefore, companies need to find an efficient and flexible way to react to these challenges. They need to gain the ability to adapt their production to short-term changes in the market with as little loss of time, effort, costs and performance as possible [11], [12]. This goal can be achieved by implementing the concept of energy flexibility, which analyses the factory's energy consumption behavior and enables its production systems to align their demand to a given scenario [11], [13].

This paper provides a first approach towards an energy-supply-orientated production planning. Within this approach, the possible supply alternatives for a factory will be discussed and integrated into the production planning process.

II. ELECTRICAL ENERGY IN PRODUCTION PLANNING

A factory's electrical energy consumption can be described by the accumulated power needs of each electrical consumer, i.e. all machines within the factory. The consumers can be categorized as kinds of equipment whose power needs are linked to the production process, like a milling machine or an oven, and those whose power needs are not or not directly linked, like air condition or illumination [14]. In the metal machining industry, equipment with a direct linkage to the production process requires 66% to 87% of a factory's power [15]. Therefore, an energy-supply-orientated production planning has an impact on the power consumption behavior of a factory by implementing the idea of energy flexibility.

In contrast to flexibility, energy efficiency in production planning has been researched for more than a decade, starting with [16], who formulated an ecological-orientated operations management. Bonneschky [17] developed an Energy-Key-Performance-Indicator-based system for production planning and control. Using adapted planning algorithms, [18] compared an energy-efficient scheduling method with conventional planning procedures. In addition, [19] implemented an energy-orientated scheduling approach for parallel identical machines in order to reduce energy costs and emissions. All approaches mentioned have in common that they achieve energy efficiency by reducing the overall power demand or avoiding expensive energy peaks. In contrast to energy efficiency and peak load management, energy flexibility aims at an adaption during the day according to variable energy prices of the spot market or the availability of on-site generation possibilities. The goal is to generate an energy-cost-efficient production schedule which considers all energy supply alternatives. Trying to answer how to operate with overall energy availability and volatile energy costs, recent publications focus especially on machine scheduling [7], [20].

Machine scheduling represents the final planning step before the real production process starts. In order to make the scheduling more flexible, buffers or unused capacities are required. This results in inefficiencies, primarily on a day with low power prices and high on-site availability. In order to gain

a holistic planning perspective, this paper assesses the possibilities of power supply and the relation to the medium- to short-term production planning process.

Production planning in general can be divided into program planning, demand planning and manufacturing planning [21]. Within this sequence, medium- to short-term planning procedures include lot sizing, time and capacity planning as well as finally machine scheduling [22]. The main task of a planning system is to harmonize performance aspects, prominently time and costs [23]. Fig. 2 shows a generic production planning procedure. Now, aspects of power demand, costs and availability need to be integrated into the sequential planning procedures. This can be achieved by formulating the resource electrical energy as a limited capacity.

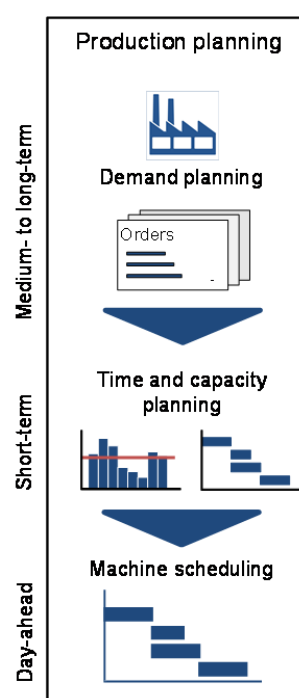


Fig. 2 Generic planning process

III. POWER DEMAND INTEGRATION IN PRODUCTION PLANNING

In the given scheme, the planning procedure uses specific methods in order to translate customer orders into a production schedule. The first step is a gross planning. Therefore, orders are combined to lots. These lots request specific resources at a specific time. The availability of resources is determined by the shift schedule, which formulates an operation timeframe for a specific resource. The shift schedules are the basis for the time planning and capacity planning and aim to harmonize lot sizes, time restrictions and given capacities. The result is a machine schedule, in which specific lots are assigned to specific machines within set timeframes. During the planning process, production machines and auxiliary equipment are seen as planning objects which are to be included into the planning process because of their demand for a certain amount

of energy. Fig. 3 illustrates the planning process, power demand and the methods of planning, all of which are influencing the resource usage and therefore the power demand in the first step.

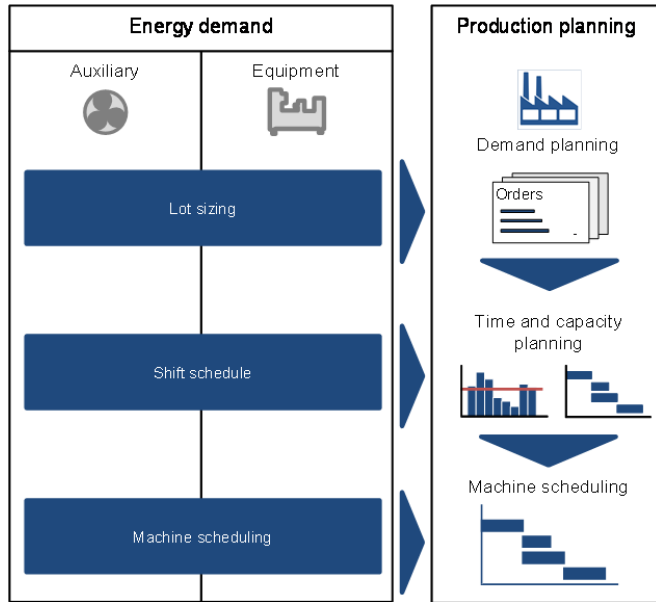


Fig. 3 Planning methods and power demand

Now, the gross methods of lot sizing and shift schedules as well as the detailed planning method of machine schedules need to be extended by adding energy demand information. Within the gross planning, a rough cumulative energy amount is required to plan the energy demand of a period. Therefore, the bill of material is used to add average energy demands to each part or product. Hereby, the lot sizing can estimate a cumulative energy demand per lot and use this information to check whether enough energy is available in the planning period.

The translation from the gross to the detailed planning is represented by the shift schedule. This medium- to short-term planning method includes information about workforce, equipment availability and in addition energy costs and availability. Every resource is provided with a workforce and energy calendar which relates to costs and availability. E.g. night shifts are more expensive than day shifts in terms of personnel, but in terms of energy costs it might be vice versa. Therefore, energy intensive equipment will be more relevant in the generation of the shift schedule. The result being used in the final step of machine scheduling is a defined capacity per equipment, namely time and energy.

A more detailed planning requires a higher resolution of information. This is why a change from energy to power demand planning is necessary in order to generate a demand curve for a certain operation step. This can be implemented by the integration of a process-specific power demand per machine state. Each state, e.g. drilling iron, drilling steel, waiting, stand-by, can now be described in terms of the specific power demand. Using the planned time per operation

step, a specific energy amount can be formulated per work sequence. Each product can have alternative work sequences with different energy demands, depending on the required resources. The work plan contains all possible work sequences and the tasks to be performed to produce goods. Fig. 4 shows a simplified data model for a gross and a detailed production planning. As a basis, a product order can be divided into the gross planning with the bill of materials and the detailed planning with work plan, work sequences, operation steps and resources. Blue colored objects in the extended data model are enriched by new energy-related information to be used in the planning method.

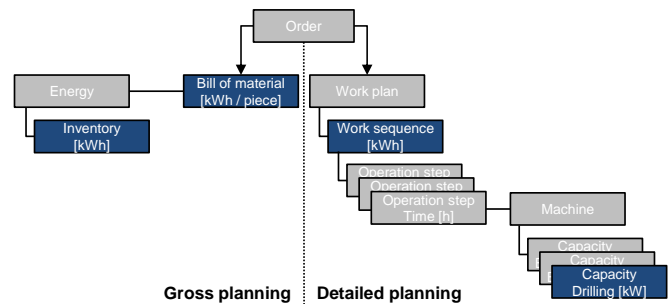


Fig. 4 Planning objects within gross and detailed planning

IV. POWER SUPPLY INTEGRATION IN PRODUCTION PLANNING

As the energy demand can be planned with the aid of the extended planning methods, an assessment of the energy costs and availability is required. Technically, the power supply of a factory can be divided into internal on-site generation and storage and the external supply via the public grid. The decision which supply alternative a factory chooses depends on the size of the factory, its industrial field and resulting overall energy consumption. Both, internal and external supplies have their own characteristics, time horizons and effects on the energy capacity.

At first, the various external supply possibilities of electrical energy are examined. Through utility companies, a factory can choose between diverse supply models. Starting from simple power contracts with energy rates and demand rates up to real-time spot market pricing, the variety of supply models are wide [24]. Factories with a high power demand, e.g. metal forming or steel casting foundries, operate directly with the energy market or via a utility company as a broker. Factories with a small or medium power demand depend on the contract offers of the utility companies, but due to the integration of the renewable energies new variable pricing contract offers appear. For the production planning process the energy market, e.g. in Germany the eex-spot-market, is the most complex alternative to integrate. The energy market will serve as an example in the following. It can be divided into a future market, a spot market and a control power market. The future and spot market offer the possibility to purchase or sell medium- and short-term energy supply. This can take place either in set blocks, namely base and peak, or in hourly blocks. In conclusion, the energy market, on the one hand, can be seen as very short-term and volatile, especially the spot-market. On

the other hand, the future market can be seen as highly projectable and stable. The control energy market offers an additional opportunity for a factory to transform a given energy flexibility into additional revenue. In this market, the factory adapts its power demand to the public grid during the production day. Therefore, given time frames are auctioned beforehand. Table I summarizes the different energy markets and their relation to the production planning process. Fundamental for the modelling of the market information are the time horizon, the prices and the influence on the given capacity.

TABLE I
ENERGY MARKET

	Time horizon	Prices level	Influence on capacity
Future market	Up to one month ahead	Daily-basis	Buy / Sell
Spot market	Up to one hour ahead	Hourly-basis	Buy / Sell
Control energy market	Up to one day ahead	Auction-basis	Provision

TABLE II
ON-SITE GENERATION

	Time horizon	Costs	Influence on capacity
Continuous power stations	Medium- and short-term	Generation-based	Increase / Decrease within technical limits
Fluctuating power stations	Short-term forecast	Non generation-based	Increase once forecast available
Energy storage	Medium- and short-term	Generation-based	Increase / Decrease within technical limits

Besides the public supply, a factory has the opportunity to generate energy on-site. The internal supply can be divided into conventional generation, e.g. with gas-turbines, in fluctuating generation, e.g. with solar-power, and in storages, e.g. batteries. Conventional generation is highly projectable and therefore suitable for the medium-term and short-term planning, because of the known technical limits. With this kind of generation, it is possible to shift capacities within these given limits in order to enable energy flexibility. Storages can help to quickly adapt the factory's power demand and supply. Due to the currently high costs of storage systems, this can be seen as a theoretical alternative. In contrast to these possibilities, fluctuating generation cannot be integrated into the medium-term planning. This is due to the fact that the generation of energy is not guaranteed and can only be assumed by forecasts. These forecasts are only available for a short timeframe. Therefore, the given information of the assumed power amount can only be integrated into the planning process on short notice. In addition, the generated energy by fluctuating power stations must be used, either in the production process or by using storage systems. This requires increasing the energy capacity on short notice. The information for the planning process differs from the public supply. Instead of energy prices, energy costs have to be considered. For conventional generation and storages a specific cost function can be deployed. Fluctuating power stations have fixed costs, but no generation-related ones.

Therefore, no cost function can be deployed. Table II briefly summarizes the different on-site generation alternatives and their relation to the production planning process.

Integrating all information into the production planning process, four areas of action can be identified. Medium-term, the external supply can be purchased on the future market. The planning concerning the conventional power stations as well as the storage systems can also be done in the medium-term. In the short-term, this planning can be adapted as soon as the fluctuating generation forecast is available. Now, the conventional generation can be adjusted, the new storage plan be deployed or energy be traded on the spot-market. One day before the production starts, the last adjustments can be performed on the energy market. As a result, a balanced supply plan is generated according to the demands of the factory resources. Fig. 5 illustrates the additional energy supply information for the production planning process.

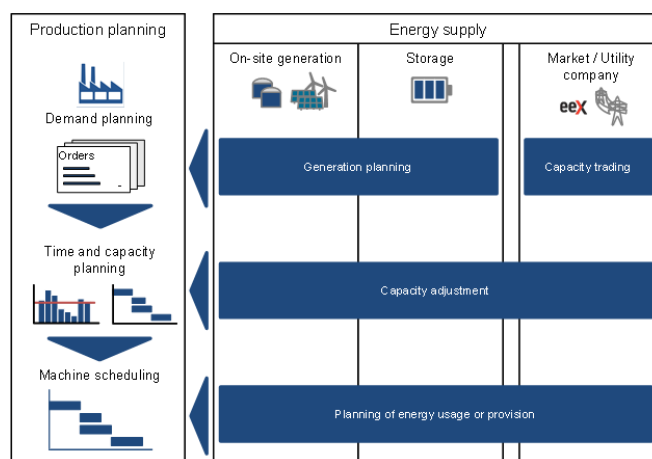


Fig. 5 Production planning and energy supply

As a result, an energy plan and a production plan are being deployed. The energy plan consists of the detailed information on how much energy is available for the production in which specific timeframe. The production plan details where the available energy is used, respectively by which machine. Both plans are ideal-theoretic and can only be seen as a reference for a production. Therefore, the plans are considered by the production control in order to release and monitor the resources and intervene as soon as deviations appear during the production process. Thereby, the concept of energy flexibility can be implemented into production planning and control.

V. ORGANIZATIONAL MEASURES WITHIN THE PLANNING PROCEDURE

In collaboration with research and industrial partners, specific measures have been identified in order to enable the idea of energy flexibility within production planning. Besides technical options, e.g. switching the energy source from on-site generation to public supply or using storage systems, several alternatives for the planning methods have been developed, all of which have an impact on the energy demands

of a factory. These are structured by the presented methods of lot sizing, shift schedule and machine scheduling.

The lot sizing aims to generate economical lots by considering costs of operation, setting-up and inventory. In addition to the conventional costs, three energy costs are taken into account for the optimization problem:

- Average ramp-up energy costs
- Average operative energy costs
- Average stand-by energy costs

By considering these costs, lot-sizes differ depending on the energy costs and energy availability. Especially the relation between energy costs and inventory costs is a highly valuable assessment for energy intensive operations.

The shift schedule provides information about machinery and worker availability. This is used to generate fixed capacities for the lots in order to distribute the lots among the available equipment. With an energy-supply orientation, new information is added to the capacity optimization:

- Market or utility company costs of energy for a specific time frame
- Availability of on-site energy generation for a specific time frame

This information is combined to an aggregated energy capacity schedule per shift. This capacity schedule can block certain time frames for energy intensive equipment within a shift, if the resource is not critical, e.g. a bottleneck for the production process. Therefore, the capacity of specific equipment is not only determined by the theoretical operation time, but also by the energy cost efficiency.

Within the machine scheduling, several options are available to manipulate the energy consumption short-term:

- Using buffers within stations
- Changing the sequence of lots
- Postpone the start of operation
- Postpone shift breaks
- Switch shifts
- Interrupt options

These alternatives are used for solving scheduling problems in order to develop an energy-orientated schedule. The goal is to use given energy capacities within a set interval. If the energy demands cannot be held in the interval, the technical options are taken into consideration to compensate the deviation if necessary.

VI. CONCLUSION AND OUTLOOK

The provided approach of an energy-supply-orientated production planning integrated both energy demands and energy supply alternatives. A generic production planning process has been used as a basis to structure demand, supply and planning methods in order to enable the concept of energy flexibility within production planning. In future works, detailed descriptions of the planning methods need to be presented as a validation. Fig. 6 arranges the supply alternatives, the planning process and methods in a time-based relation towards the start of production.

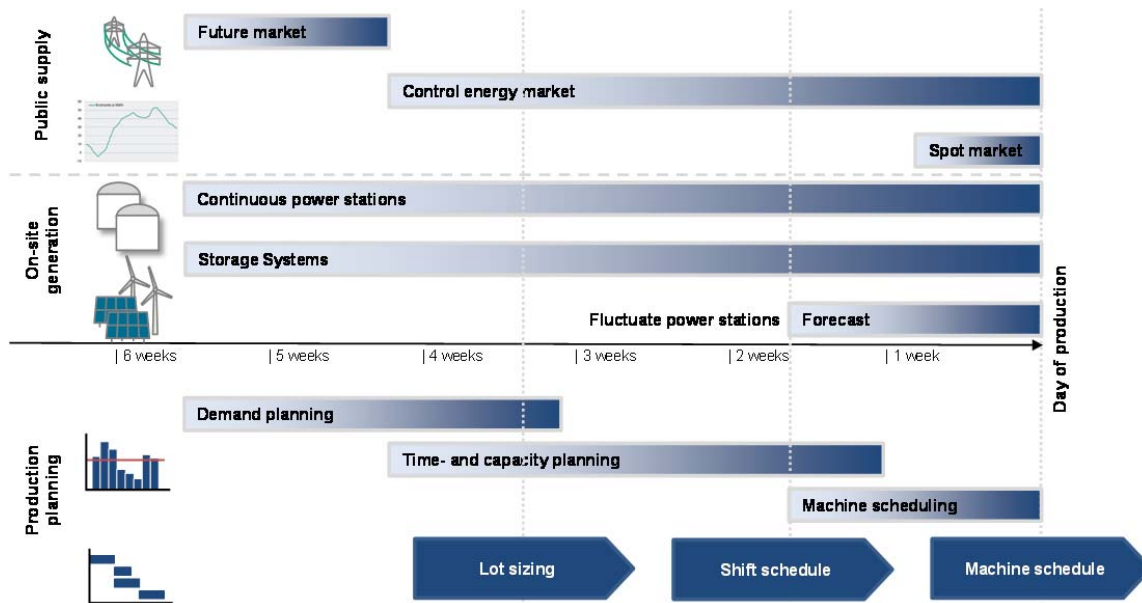


Fig. 6 Time horizons of production planning and energy supply

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