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Integration of On-site Energy Generation into Production Planning Systems

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Abstract

Due to the energy turnaround in Germany, the costs for energy are peaking year by year. As a result, industrial companies are investing in on-site generation, preferably from renewable sources like photovoltaic. Companies can profit from an on-site usage in order to hedge price volatility. Therefore, the fluctuating on-site energy and the public energy supply need to be synchronized to the production demand in an efficient way. In order to use the fluctuating renewable on-site generation, a transformation of the production organization and the production planning systems is needed towards the concept of energy flexibility.

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Keywords: production planning and control, energy, capacity planning, scheduling, flexibility

1. Introduction

The German exit from nuclear and fossil-fuel energy poses a challenge for industrial enterprises. Increasing costs and decreasing service security cause essential fields of action [1] especially in terms of production planning and control. Thus in recent years, manufacturing companies in Germany have steadily increased the use of on-site generation in order to provide for their energy demand themselves. The reason for this development is the state subsidization, particularly of renewable energies, leading to cost advantages compared to obtaining the power from the public grid. In addition, an on-site generation results in a greater independence from external utility companies [2]. The status quo, where the energy produced with renewables is sold and fed into the public grid and where the energy needed was obtained from the public grid in return, is becoming less profitable, due to rising energy costs and falling compensation for energy fed into the grid. Therefore, numerous companies switch over to consume the energy of on-site generation themselves [3]. This approach, called on-site generation, covered 9 % of the overall industrial and private energy demand in Germany in 2014. More than 60 % of the companies trusted on power generation by photovoltaics in 2013, 14 % of the companies made use of wind power. Hence, a significant portion of on-site generation is based on renewable energies, which are fluctuant over time and in quantity [3]. That is why the warranty of a reliable and cost-efficient energy supply is to be viewed as a real challenge. In order to master this challenge, the on-site generation must be integrated into production planning and control processes. The power demand is then synchronized with the on-site generation’s energy supply. Afterwards the production planning takes measures to adapt the power demands, for example buying additional power from the public grid or delaying the production to a timeframe with lower energy costs due to an energy surplus. Since energy storage allows the compensation of energy surpluses as well as energy shortages, its application should be considered in the production planning and control.

An integrated concept of on-site generation can contribute to cost savings concerning the power supply of the manufacturing.

2. Energy as a Resource in Production Planning and Control

Production planning and control systems support manufacturing companies in aligning logistic and economic

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goals in times of ever-expanding complexity and variety of products. Production planning and control comprises two sectors: Production planning, dealing with long-term and short-term planning processes, and production control, aiming at approving and monitoring the production orders processed at any time [4]. In the production planning, there are individual, consecutive process steps, for example the planning of schedules, the planning of volumes, the planning of dates and capacities, as well as the machine scheduling. Each of these steps contributes to the overall frame, in which the manufacturing schedule is being continually rendered more precisely [5]. In the past, numerous authors in the scientific literature have dealt with integrating energy as a resource into the production planning and control. However, their approaches focus on integrating energy efficiency into production planning [6]. A new approach brings the optimization of the way of obtaining energy into focus. Here, the examination is limited to the public grid; the approach does not consider on-site generation nor the use of on-site generation and energy storages [7]. Yet, integrating the energy market into the production planning and control systems forms the basis for considering on-site generation and energy storage.

3. On-site Generation and Energy Storage

Power plants differ in their characteristic features and show distinct patterns in terms of their energy supply's constancy, which allow a categorization in continuous and fluctuating power plants. Energy storages can be classified into functional storages and power storages, according to their intended use. The aforementioned classification in categories forms the basis for the integration into production planning and control systems.

3.1. Continuous Power Plants

Continuous power plants produce electricity in a largely steady manner by employing constantly accessible energy sources that are not subject to volatility in their amount. Such energy sources can be stored in reservoirs or else their supply is bound by a contract. Important continuous power plants are for example block heat power plants, gas-fired or coal-fired power plants, and power plants using cogeneration of heat and power [2]. Continuous power plants show a constant operation, they have constant key performance indicators (KPIs), which are valid for both the long-term and the short-term planning. By offering this precise information about their production of energy, the power plants allow for planning well in advance. Continuous power plants usually have an optimum operating point at which they achieve the best efficiency factor. The amount of energy produced at this point is measured in *kWh* and is to be embedded into the production planning and control system. However, the power plants remain controllable, i.e. their operation can be accelerated as well as decelerated, depending on the current power demand. Hence, apart from the optimum operating point, they have a maximum and a minimum performance indicator [8], the latter of which is the result of the power plant's deceleration. The production planning and control must be aware of this controllability, in order to demonstrate the production engineers their scope of action.

Moreover, continuous power plants feature calculable operating costs, which are significantly dependent on the fuel costs. These operating costs must as well be integrated into the production planning and control system. The energy generation is integrated using so-called energy plans, which contain all the relevant information concerning the amount of energy produced and thus provide a basis for the production planning and control.

3.2. Fluctuating Power Plants

Fluctuating power plants, on the other hand, do not provide a permanent and guaranteed energy supply, since their energy sources are not steadily available, due to the unsettled weather conditions. Consequently, the amount of energy generation cannot be controlled and the amount can only be projected to a limited extent. In contrast to the continuous power plants, the fluctuating power plants do not offer constant characteristic values in terms of their energy generation. Thus, the planning is based on long-term and short-term forecasts of the energy yield, typically covering the future 12 months to 4 days, respectively [9]. However, the forecast values measured in *kWh* are not reliable; instead they represent the average in a range of calculable variations of the energy amount [10]. The shorter the forecast horizon gets, the higher the reliability, and thus the narrower the range of variation [11]. Figure 1 illustrates this development.

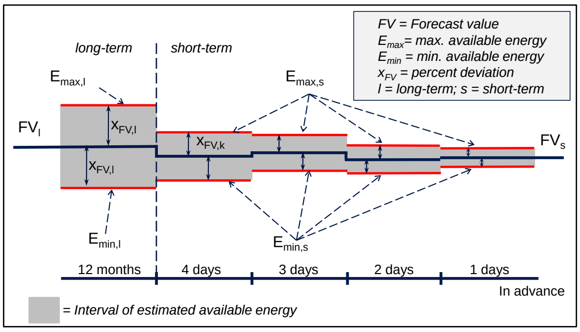

Figure 1: Development of estimated available energy of fluctuating power plants

In order to integrate the fluctuating power plants into the production planning and control systems successfully, the forecast values must be transferred to the system, adding the annotation that they are not reliable. Since the forecasts keeps getting more reliable as the time of production approaches, the production planning and control system must update the forecast values regularly, in contrast to the procedure with continuous power plants. The result is a detailed production planning and control at any time. The integration of the forecast values also considers the aforementioned energy plans.

The greatest advantage of fluctuating power plants is their use of energy sources that are free of charge. If the investment and the maintenance expenses are neglected, there are no use-based energy generation costs. This fact should also be included in the production planning and control system.

Figure 2 provides a summary of both power plant categories.

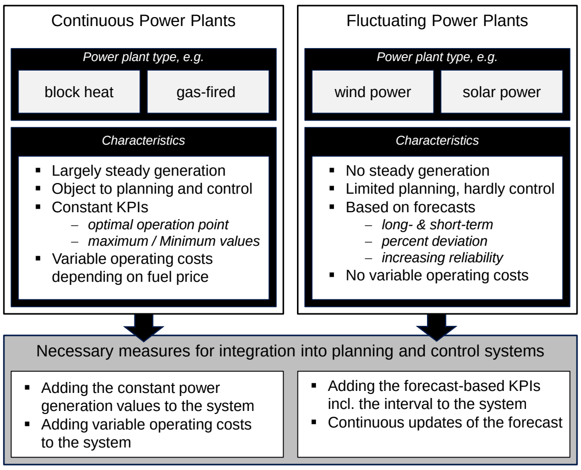

Figure 2: Summary of continuous and fluctuating power plants for the production planning and control

3.3. Functional Storages and Power Storages

Energy storages are important for compensating temporal gaps between energy generation and energy demand [12]. Two approaches can be differentiated, power storages and functional storages. If a surplus of electrical energy is available and the electrical energy needs be used at some later point, power storages can be employed, e.g. in the form of electrochemical energy (e.g. batteries) or in the form of mechanical energy (e.g. pumped storage power stations). Here, the surplus of electrical energy is being stored in order to be accessible at a later point of energy shortage. In either case, the energy is reconverted into electrical energy again [13]. These power storages feature precise key performance indicators, e.g. peak performance, storage duration, or storage costs [14], all of which are integrated into the production planning and control system to serve the production engineers as a planning basis.

The functional storages convert the energy in other forms of energy or media that is used in the actual production process, e.g. heat or compressed air. There is no reconversion into electrical energy. The production process should use thermal and compressed air storages merely on short notice, without a systematic planning, so these storages are more in the focus of production control than planning.

Figure 3 provides a summary of the important characteristics of energy storages. In general, there is great benefit in planning the usage of energy storage well in advance, since the long-term information on energy demand and supply is not precise enough. Thus, this information can be used in the production control for a short-term synchronization.

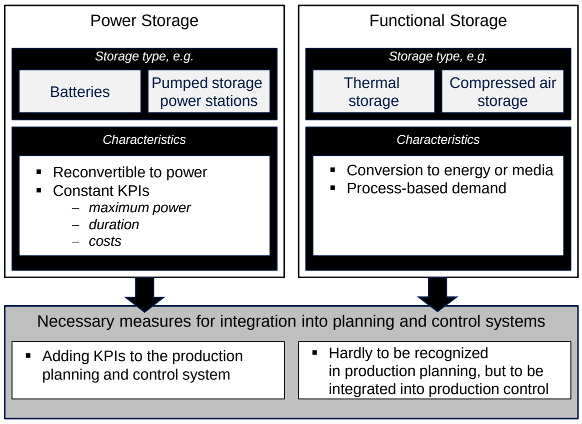

Figure 3: Summary of power and functional storage systems for the production planning and control

4. Model of Integration

The various measures for planning the on-site generation in the production planning and control arise from the different categories of power plants and energy storages. The constantly adapting process of production planning has a time horizon of up to one year, in which the planning keeps being updated in greater detail in terms of shorter time frames and patterns [15]. When it comes to production control, processes can be detected that provide more and more details as time goes by. Even the integration of obtaining the energy into the production planning and control follows this principle. A first assessment of the energy demand is carried out twelve months in advance using a monthly pattern, a second assessment with an hourly pattern follows then only a few days ahead of production [7]. In case of covering the identified demand by using on-site generation instead of the public supply, these time patterns serve as guidelines when integrating on-site generation and power storages into the planning processes. Figure 4 shows the procedure of this integration, comprising the aforementioned energy plans that contain information on the expected amount of energy production.

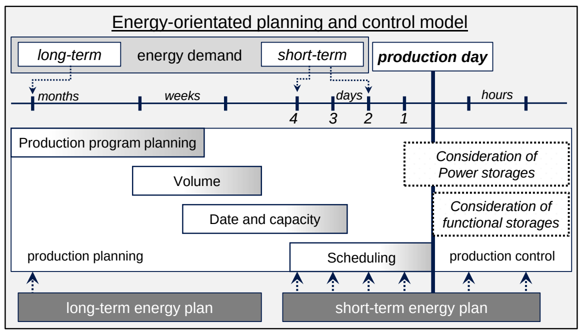

Figure 4: Energy-orientated planning and control model with focus on on-site power generation

4.1. Long-term Energy Plan Development

Twelve months before the production date, both continuous and fluctuating power plants provide data with a monthly pattern concerning the projected amount of energy production of each power plant [16]. The long-term energy plan illustrates this aggregated data in the unit *kWh* and compares it to the roughly estimated energy demand of the production lines, again in *kWh*, as shown in Figure 5 using fictitious power plants. Whereas the combined heat and power system running at its optimum operating point provides a constant amount of electrical energy, the monthly averages of the solar power plant sometimes show considerable variations due to the seasonal changes. The given value for the solar power plant is based on the forecast value. However, since this average cannot be guaranteed and is subject to the aforementioned variations, the actual amount of energy produced in the fluctuating power plants can differ and be above or below the forecast.

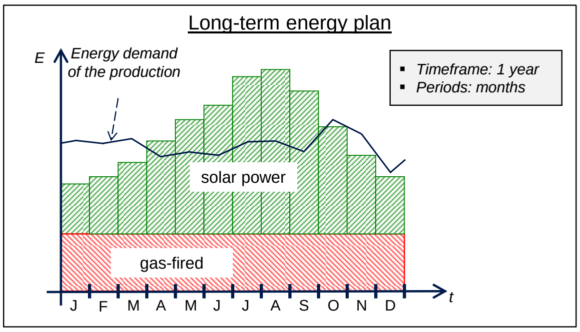

Figure 5: Exemplary long-term energy plan

Yet, this average value is most suitable for the long-term estimation concerning the energy supply. In order to allow the production planning to consider this uncertainty, a differentiation between continuous and fluctuating power plants need to be performed by adding a different visual appearance in the energy plan. Then the share of the uncertain energy can be pointed out in the total energy amount. The long-term energy plan helps to take measures, e.g. a long-term purchase of additional electrical energy from the public grid or an additional on-site generation system.

Here, the long-term planning of energy storages can be neglected.

4.2. Short-term Energy Plan Development

A few days before the production start, the production planning and control system is provided with detailed information on the energy demand. Using the short-term energy plan, the information can be compared to the equally updated and equally more precise data concerning the projected amount of on-site energy production. Whereas the characteristic values of the continuous power plants remain consistent, a new and more specific data can be received up to four days before the production with regard to the fluctuating power plants and their estimated energy generation. This four day horizon is split into intervals of eight hours, just like the short-term energy plan. Figure 6 shows a short-term energy plan that contains an aggregated amount of energy.

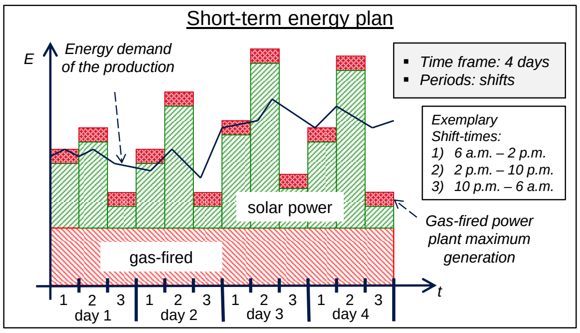

Figure 6: Exemplary short-term energy plan

In addition to the optimum operating point of the continuous power plants, it is reasonable to consider their maximum output in the short-term energy plan in order to show the planning engineers their scope of action concerning the adjustment of energy generation at short notice. The minimum power output of zero *kWh* is obvious. The integrated value of the fluctuating power plants is the forecast value, in accordance with the long-term energy plan. However, now this forecast value is more reliable.

As mentioned above, this reliability is increasing day by day. Due to this, a daily update of the short-term energy plan can enhance the planning's precision. On the day of the actual production process, the production control system is responsible for the further coordination. Therefore, the forecast patterns must be more precise and split into shorter intervals of hours or 15 minutes.

With the help of the new information, the production planning and later on also the production control can plan the use of energy storages. The given characteristic values enable the production engineers to use energy storages in a sensible way. The production control is responsible for the spontaneous application of the functional storages. Furthermore, continuous power plants can be regulated in their performance and electrical energy can be bought or sold to the public grid.

4.3. Adapting the Data Structure of Production Planning and Control Systems

In order to implement the compiled measures in production planning and control systems, the systems' data structure needs to be expanded. Again, the basis for this is the integration of the energy market into the production planning and control [7]. By considering energy as a resource, the production planning and control systems can compare the energy demand with the supply. This is the same process as when buying other resources on the market. The purchased energy can be viewed as stored in the virtual energy storage, enabling us to keep record of the energy amounts. If this storage is to be filled with electrical energy from on-site generation, their documentation is similar. However, it is necessary to differentiate between the various power plants in order to match the different energy amounts to their origin in the energy plan. This is why the types of the resource energy are distinguished, all of which are part of the category simply called energy, since for the production it does not matter where the energy is from. To integrate the energy storages into the production planning and control systems, so-called storage locations need to be identified and their respective characteristic values like maximum capacity, maximum storage period and storage costs. Then, the planning and control systems can use this data and coordinate its usage.

5. Application

Currently, many companies have invested in on-site power plants. The investment criteria in the past mostly focused either on base-load satisfaction, on a subsidized sell to the public grid or on combined power-heat applications. Therefore, the installed systems were uniquely planned and designed for a permanent usage facing a fixed production program respectively energy demand. By integrating the concept of energy flexibility, the production program especially the scheduling can be enabled to adapt the energy demand of a factory to volatile generation or variable prices. Therefore, the KPIs of the on-site generation need to be added to Enterprise Resource Planning (ERP) and Manufacturing Executions Systems (MES) in order to match the production based demand and the available on-site generation cost-efficiently. Including the current price information from the public grid, an integrated energy supply orientated production planning can be performed. In first applications using SAP based structures, the process from production program planning to scheduling was executed successfully.

6. Summary and Prospects

Integrating the on-site generation into production planning and control systems is an important step when coordinating the energy supply in production. Its practical implementation, however, is facing various challenges. Although the software SAP ERP allows defining energy storages as storage locations without any problems, it does not allow a storage period in the SAP standard. A redefinition of material variations can be implemented as well, but the inventory management distinguishes all the variations, so the system specific term *material* is lost [17]. Updates and add-ons for the SAP standards are necessary and are already in the making.

In order to ensure an optimized energy supply of the production, a master plan is needed. This master plan combines the obtaining of energy from the public grid with the on-site generation. Even if on-site generation can have cost advantages compared to buying electrical energy from the public grid; in some scenarios, covering the demand with an aligned combination of both can a resource- and cost-efficient solution.

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