Decentral energy control in a flexible production to balance energy supply and demand

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Abstract
A volatile energy supply sector with fluctuating energy prices poses new challenges to sustainable and cost efficient manufacturing. To ensure a stable and cost efficient energy supply in the industrial energy system, energy supply as well as the demand for manufacturing has to be balanced. The goal is to use energy when it is cheap and provide energy or use less energy during periods of high energy prices. Achieving this goal is strongly limited by ensuring the production performance especially the delivery time and the output and depends on the flexibility of the production. While smart grids provide solutions for balancing supply and demand for regional and higher structured energy networks, solutions in an industrial energy environment are missing. This paper presents the ongoing research concerned with the development of a decentral system including methods and control units to autonomously control and industrial energy system with fluctuating prices. The system will ensure production performance while decreasing energy cost through balancing energy demand and supply. For this purpose, the control units will measure the energy available inside the system. This information has to be balanced with the actual production order situation of each single machine. Based on this comparison, the control units will decide autonomously, considering different production relative parameters, to produce or to wait for more, cheaper energy in the network.

1. Introduction and Motivation
Due to a growing proportion of renewable energy sources as well as a decentralization of energy production, the energy system faces major changes and challenges [1]. The role of the consumer is in particular focus, since e.g. the increasing penetration of wind and solar power is necessitating a more active role for energy management in homes, buildings, and industries [2]. Industrial facilities are high energy consumers which are responsible to lead the change on the consumer side. The intermittency and unpredictability of renewable power generation is in sharp contrast to traditional power generation. With power coming entirely or almost entirely from the latter assets, system operators have been able to keep the grid balanced by adjusting generation in real-time in response to demand variation [3]. With unpredictability now extending to generation, imbalances in the grid may cause grid reliability issues or energy price fluctuations. Therefore, industrial facilities tend to transform its infrastructure more and more from a consumer only to an energy prosumer system. On-site energy production, consumption and storage on the one hand as well as an increasingly complex interface to the energy system on the other hand require an advanced on-site grid and energy focused production management.

2. State of the Art
2.1. Demand Side Management
Historically the energy system is dominated by large power plants, which produce the required energy quantities and balance demand and supply at any time. Due to a growing
fluctuation and decentralization on the production side, balancing supply and demand is getting more and more complex and dynamic. A more active involvement of the consumer side is not an entirely new approach. However, falling costs of communication infrastructure and embedded systems enable a “smart” and controllable consumption [4].

In the early 1980s the concept of Demand Side Management (DSM) was developed in the US and is increasingly used in Germany since the Energiewende. DSM is based on the assumption that it is more cost-effective to intelligent influence a load than to build or install new power plants or energy storage [5]. DSM includes the planning, implementation and monitoring of efficiency and flexibility measures on the consumer side to change the load profile of the consumer. [6]

The foundation of DSM are measures to increase energy efficiency. These include all permanent system optimization to increase energy productivity. Measures for flexible adaptation of the energy consumption to signals from the energy market can be described as a function of time and grid interaction and are divided into two areas (Fig. 1).

An energy optimized operation scheduling adjusts the load curve of a production system with regard to the avoidance of peak loads and the relocation of energy-intensive processes in times of favorable energy prices [3].

A temporary load variability describes a temporary measure to reduce or increase the power used [7,8]. Based on the load change signals from the power system (for example, price or control signals), which are triggered by unplanned, irregular or extreme energy economic events, this is referred to as demand response [9].

Energy optimized operation scheduling as well as temporary load variability do not primarily reduce energy consumption, but optimize the load profile based on the available energy flexibility.

### 2.2. Energy Flexibility

Flexibility refers to the ability to adapt to changing conditions. Due to an increasing complexity of production tasks and a continuous increase in product variants, production systems are in an environment that is characterized by a great uncertainty. [10] This uncertainty provides manufacturing companies with major challenges and risks. To be able to adapt to such uncertainty, companies need to have sufficient flexibility [11].

With uncertainty now extending to the energy supply, energy flexibility enables the energy consumer to adapt to changing energy prices. Different approaches to flexibility can be identified in the literature [11,12]. In this study only the approaches with a direct relevance to the developed model are considered.

#### Volume flexibility

Volume flexibility refers to the ability of a production system to economically adjust its production volume to socioeconomic constraints [13,14].

#### Route flexibility

Route flexibility refers to the possibility of a production system to produce a specific product through alternative routes or production order [11,15].

#### Product flexibility

Product flexibility is defined as a company’s ability to be able to produce different products with a short setup time [15]. Due to a growing individualization of customer requirements and an increasing complexity of products forms, product flexibility is a big step to an increasing competitiveness.

#### Machine flexibility

Machine flexibility describes the possibility of individual machines to perform various manufacturing operations with minimal setup effort. The machine flexibility may also increase the flexibility of other approaches such as the route and product flexibility, [11,15]

Based on this general approaches to flexibility, approaches to energy flexibility can be classified.

#### Interruption of production

Interruption of production describes the interruption of processes when the energy price is high. By temporarily stopping the processes, the power consumption of a production station is reduced in large measure [7]. This approach is especially critical in terms of delivery dates. The limiting factors for the interruption of production are defined through the volume flexibility as well as the delivery dates.

#### Adjustment of Stock

Adjustment of Stock describes the strategy to use store capacity depending on the energy prices. During periods of high energy prices processes can be stopped or slowed down while upstream process run on stock capacity. The limiting factors are defined through the volume flexibility, product flexibility as well as the storage capacity.

#### Adjustment of process parameters

Adjustment of process parameters can change the energy consumption of a process e.g. changing the temperature in a batch reactor. The adaptation of processing parameters describes the regulation of the process parameter according to the change of the electricity price [8]. The limiting factors are defined by the available machine flexibility.

#### Adjustment of maintenance and set-up time

Adjustment of maintenance and set-up time to periods of low energy prices, describes a time and energy sensitiv strategy of maintenance and set-up time in order to reduce the energy costs of production [7]. The limiting factor are defined through volume- and route flexibility of the production system.

### 2.3. Implementation of Energy Flexibility

To successfully implement energy flexibility in production systems, it is necessary to include production costs, quality and time in the optimization. Energy optimization can be implemented on different levels, which can be described based on grid interactions (Fig. 1). Most approaches which implement energy as a factor in the production planning...
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