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Approach for a Potential Analysis of Energy Flexible Production Systems

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Abstract

Due to the increasing use of volatile renewable energy sources in Europe and especially in Germany, companies' production systems have to be energy flexible in order to cope with changes in energy markets. Therefore, an important requirement for companies is to know about the possibilities of their production systems to adapt load. Hence, several key performance indicators for evaluating production systems have to be developed. This work provides an approach for the evaluation of energy flexibility based on the availability of different machine states in terms of different energy levels. Furthermore, several time dimensions of energy flexibility are taken into consideration. The approach is structured into five different steps. The first step describes the identification of measures for adapting the load of a station to the current energy supply. In order to evaluate the potential of a production system, it is necessary to analyze the combination of different measures of different stations – so called bundle of measures. Therefore, the second step provides a strategy for the enhancement of load adaption by bundling at least two measures. Beside this, it is also possible to improve the temporal characteristics of measures resulting from technical and organizational restrictions by using another bundling-strategy, as described in the third step. The fourth step describes a strategy to reduce the effects caused by interactions between the stations that come along with the execution of measures. The last step describes the evaluation of the bundles with different key performance indicators.

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1. Introduction

In order to save the environment, the use of natural resources, i.e. renewable and non-renewable raw materials and environmental media, such as air, water, and soil etc., has to be reduced [1]. Nowadays, mainly non-renewable resources are used to generate electrical energy [2]. Therefore, the environment can be preserved by using renewable resources for energy generation such as wind, geothermal, tidal, and solar energy. Thus, energy generation using these resources is driven by environmental requirements [3]. Therefore, there is a decreasing system reliability in using renewable energies, as electrical energy cannot be stored economically at the moment and energy supply and demand have to be in balance at all times. As manufacturing industries are one of the major consumers of electrical energy, they have to contribute to the implementation of renewable energies in the energy system by adapting their energy demand when system reliability is jeopardized [4]. Therefore, companies have to be energy flexible and have to know their energy flexibility potential.

2. Fundamentals of evaluating energy flexibility

2.1. Definitions and focus

The major share of the consumed electrical energy is used to generate mechanical energy, e.g. in a machine tool, and for the generation of process heat. Therefore, most of a factory's electrical energy is used in production [5].

Based on the scheme provided in figure 1, it is obvious that the energy demand of a factory can only be adapted by changing the energy demand of several working stations. Therefore, the focus of this paper is on the evaluation of the energy flexibility of a production system. Referring to classical flexibility definitions, energy flexibility in this context can be defined as the ability of a production system to

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adapt itself fast and without remarkable costs to changes in energy markets [6].

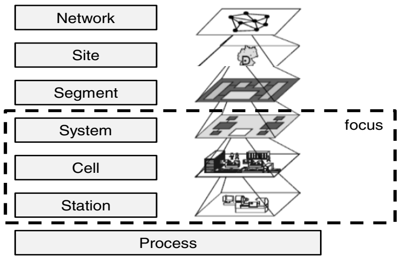

Fig .1. Levels of a production [8]

2.2. Pricing models for the integration of energy flexible production systems into the energy system

To maintain the balance of the energy grid, the adaptation of the energy demand to the availability in the grid is a promising approach. In literature this is known as energy demand response. According to the U.S. Department of Energy, demand response can be defined as follows [9]:

Demand response is a change in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments […] when system reliability is jeopardized.

As mentioned in the definition, demand response instruments can be categorized into two basic groups: the price-based demand response and the incentive-based demand response programs. Price-based demand response gives customers time-varying rates that reflect the value and costs of electricity at different time periods, for example, real-time pricing (RTP). These tariffs can also be more static like Time of Use (TOU) and Critical Peak Pricing (CPP) tariffs, in which prices are fixed for longer blocks of time [10].

The second group of demand response instruments is incentive-based. Customers can participate in these programs in addition to normal tariffs. By using incentive-based programs, participants receive a payment when reducing or enhancing load at times, requested by the program sponsor, or triggered either by a grid reliability problem or high electricity prices [11]. The different types of incentive-based demand response instruments vary by the amount of time the customer has in advance in order to commit his willingness to adapt his power demand and how the incentive payment is done.

The presented demand response instruments provide production systems with the opportunity to achieve energy cost savings compared to fixed price tariffs by consuming less energy when energy costs are high and enhancing energy demand when energy costs are low. This requires a knowledge of the production systems' energy demand and the possibilities to adapt it.

2.3. Energy flexibility - a literature review

There are many approaches in literature concerning energy flexibility in manufacturing engineering. These approaches can be categorized into two groups – the implementation of energy flexibility and evaluation.

One approach concerning the implementation of energy flexibility in production planning is the idea of formulating the resource electrical energy as a limited capacity. The author describes energy-supply-oriented production planning on the basis of a generic production planning process [12]. Other authors present a method for real-time control of manufacturing systems with several processes and intermediate buffers to increase the utilization of on-site generated variable renewable energy without compromising system throughput [13]. Other approaches focus on short-term production control. They deal with the use of energy flexibility to align energy demand in production with energy supply while maintaining logistic goals [14] [15].

Before companies make the decision to implement these concepts, they need to know the benefits and costs of using their flexibility. Therefore, the literature provides several approaches to evaluate energy flexibility. One approach describes a method that calculates a key performance indicator for a station concerning the time, cost and state dimensions of flexibility [16]. Another one focusses on the mathematical calculation of energy flexibility by taking the load of a production system into consideration without taking the material flow, stations, buffers and their interactions into account [17].

As these are relevant factors for most companies, it can be noticed that there are no sufficient approaches that allow for an evaluation of energy flexibility in the manufacturing industry on the production system level (figure 1).

3. Conception of the method

In order to enable the evaluation of energy flexibility in the manufacturing industry, a method for analyzing the energy flexibility potential of production systems shall be developed. Flexibility potential is determined via the characteristics of the available adaptive measures. Those adaptive measures are referred to as Energy Flexibility Measures (EFM). An EFM is described as an intentional action for executing a change of state in order to adapt the load of a station to the current situation on the energy market [16]. It is assigned to an initial state of a production station and aims for a certain target state.

3.1. Characteristics of Energy Flexibility Measures

Analyzing EFMs, a set of eight characteristics, mainly derived from three flexibility dimensions, can be used.

The most decisive factor concerning the market potential of an EFM is the *load adaption* ΔP^{EFM} that can be realized. It results as the difference between the power levels of the initial state and the target state and can be either positive or negative. For a simplification of states, the power level is modeled as a constant mean value excluding short-term changes. The amount of load adaption heavily determines the revenue that can be generated by executing the EFM. As a consequence, the market revenue of an EFM can be increased