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Design principles for energy flexible production systems

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Abstract

The change of the energy supply from conventional energy sources to renewable ones is a challenge for the whole society. It is a well-known fact that this alteration causes increasing energy volatility and therefore requires a change in energy use. When it comes to production matters, energy is yet a resource which is available immediately on-demand. In the future, energy needs to be considered as a resource during the production planning process. Therefore, certain design principles for energy flexible production systems must be developed and will be presented in this paper. Finally, the paper also shows in which way the design principles affect the specific energy flexibility characteristics.

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Keywords: Energy Flexibility; Design Principles; Production Systems; Renewable Energies

1. Introduction

With the agreement of the United Nations Climate Change Conference in 2015 [1], following up the Kyoto Protocol [2], the promise to reduce the carbon dioxide emission became once more the center of public attention. In 2007, the EU's climate and energy package has been passed in order to reduce the negative environmental impact of human activities. These political objectives provided the impetus to take initial steps towards reducing the energy consumption and increasing the effort to build up renewable energies.

The Kyoto protocol as well as the EU climate and energy package were the trigger for the German government to pass a concept for an ecofriendly, reliable and affordable supply of energy in 2010 [3]. At this point, nuclear power plants were still meant as a bridging technology to diminish the use of fossil fuels. After the nuclear disaster in Fukushima in 2011 however, the energy concept had to be reconsidered. Until 2022, all nuclear power stations are going to be switched off and consequently, the share of renewable energies must be increased up to 80% of the power generation. In 2015, nine of 19 commercial nuclear power plants were still operating and the share of renewable energy reached the mark of 30% [4].

Subsequently, the use of volatile energy sources poses new challenges for the society. Different technologies to balance energy supply and demand, like energy storage at grid level or the use of gas-fired plants, are discussed [5]. Because of the high industrial energy demand in Germany, which is 47% of the annual energy demand [6], the flexibility of the industrial energy demand presents a relevant element to ensure a safe energy supply. The adoption of the industrial energy demand can stabilize the regional energy grid for short-term. These compensation measures offer companies the possibility to reduce their energy costs by taking advantage of fluctuating electricity prices. With the increase of renewable energies, further potentials than the existing are required to ensure a safe, affordable and sustainable energy transition. Therefore, it is necessary to design energy flexible production systems. For this purpose, this publication proposes a systematization of design principles and their impact to increase energy flexibility potentials.

2. Definition and description of energy flexible production systems

2.1. Energy flexibility

The term energy flexibility describes the ability of a system to adapt its energy demand in consequence of a changed energy

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supply [7]. In contrast to the existing types of aggregated flexibility, the energy flexibility is an input oriented. Based on the hierarchy presented by Sethi & Sethi [8], the energy flexibility can be structured in a similar way. It also depends, as the market or production flexibility, on the volume, the route and the product flexibility [9]. As each of these types of flexibility influence organizationally the energy demand of the production system, they are called system flexibility. Similar to the flexibility properties, the energy demand is a feature of the plant and the process and therefore forms the basis of energy flexibility. Consequently, the energy flexibility can be described as the forth aggregated flexibility, based on the structure of Sethi & Sethi [8] (see Fig. 1)

By explaining the definition and the classification of energy flexibility, the core dimensions will be highlighted in the following. The range of energy flexibility is described by the two dimensions, power change and duration of the production system configuration or station state. The activation or deactivation of different states is defined as speed time. The third dimension of energy flexibility is the ability of action including the costs to use energy flexibility measures but also the system complexity and controllability to adapt the production system to the energy supply. The three dimensions depend on one another. Therefore, to increase the energy flexibility, each of these dimensions must be analyzed and solutions have to be developed under this premise.

2.2. Energy flexibility potentials

Designing energy flexible production systems means to adapt the structural characteristics determining an energy-oriented factory operation. The above described energy flexibility is the property of the production system at a given time to adapt to changes in the energy supply. In addition, the term energy flexibility potential describes the total amount of flexibility measures. Thus, the energy flexibility is a subset of the energy flexibility potential which is used in a targeted manner depending on the existing system state.

In regard to research results for energy efficient factories [10], energy flexibility potentials are classified into theoretical, technical, economic and used potentials [11] (see Fig. 2). The theoretical potential initially describes the change in the power consumption only taking into account the physical properties. The technical potential for energy flexibility already considers product and equipment specific restrictions. In regard to the annual output volume, the accrued flexibility costs, the energy cost reduction and the requirements for throughput time and delivery reliability, the economic potential is obtained. In addition to the monetary balance, the economic potential also includes the feasibility that represents a non-monetary expense. The used potential is the amount of flexibility potentials which is contractually marketed or used in the context of energy-oriented production planning and control.

In order to increase the energy flexibility potential, the technical and economical potentials must be extended (see Fig. 2). Therefore barriers between the theoretical and technical or between the technical and economic potential must be eliminated. For this purpose, the impact factors determining the different flexibility are identified and will be presented within an impact network in Section 5.

3. Requirements to design energy flexible production systems

In the last years several surveys have been published analyzing the energy flexibility potentials of different companies and industrial sectors [12–14]. On the one hand, these potentials are used for an economic valuation by a sector and national broad extrapolation of the flexibility potentials. On the other hand the impact of an energy oriented production operation on the company success has been analyzed by the use of existing energy flexibility potentials [15–18]. Because of the uniqueness of each company the energy flexibility potentials cannot be directly adopted by other companies. Taking this point into consideration, the company specific possibilities of energy flexibility potentials have to be built up in a structured way.

By virtue of the structural changes, the increase of energy flexibility is part of the factory planning process. In this context, the production system has to be defined based on the desired production program considering the future production operation.

During the design process of production system the planner has to develop different solutions to increase the energy flexibility potential of the production system. In relation to the flexibility theory of Kaluza & Blecker [19] and to support the design process for flexible production systems, it is necessary to analyze the requirements of the emergence of flexibility and to identify specific fields of action. Regarding the design of en-

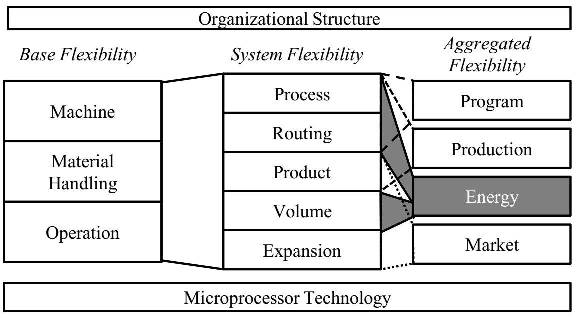

Fig. 1. Classification of flexibility in production systems (based on [8]).

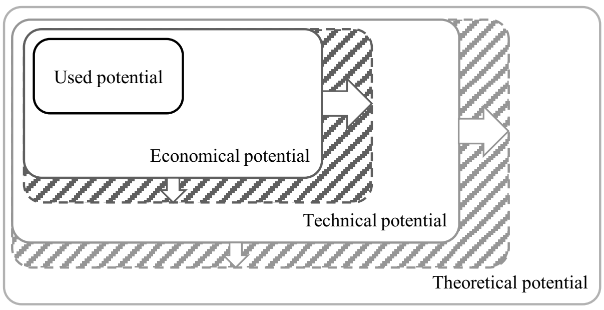

Fig.2. Classification of energy flexibility potentials (based on [11]).