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ScienceDirect
Procedia CIRP 63 (2017) 254 – 259
www.elsevier.com/locate/procedia

The 50th CIRP Conference on Manufacturing Systems

A systems engineering based method to increase energy flexibility

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Abstract

The change of the energy supply from conventional to renewable energy sources is a challenge for the whole society. It is a well known fact, that the alteration of energy supply from conventional towards renewable sources causes increasing energy volatility. This requires a change in energy use. When it comes to production matters, energy is a resource, which is available immediately on demand. In future, energy will become a resource, which needs to be considered during the production planning process. The adaption of the energy consumption to the available amount of energy affects the material flow and the order processing. Today, manufacturing systems exhibit a limited amount of energy flexibility caused by their interlinking. The use of possible flexibility potentials, manufacturing systems themselves or their structure needs to be adjusted. For this purpose measures for increasing the energy flexibility have to be built up in a structured way. Based on the systems engineering an approach to design energy flexible manufacturing systems has been developed and will be presented in this paper.

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems

Keywords: Energy flexibility, systems engineering, factory planning

1. Introduction

With the agreement of the United Nations Climate Change Conference in 2015 [1], which follows 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 and to implement them.

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 environmentally friendly, 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. But after the nuclear disaster in Fukushima in 2011, the energy concept has to be reconsidered, which means that until 2022 all nuclear power stations are going to be switched off and consequently, the share of renewable energies have to be increased up to 80% of the power generation. In 2015, nine nuclear power plants were still operating and the share of renewable energy cracked the mark of 30% [4].

Subsequently, the use of volatile energy sources presents new challenges to the society. Therefore, in the past years the research field in adapting the energy consumption to the energy supply has been developed. First theoretical and practical results show, that an energy flexible factory operation is possible and necessary [5,6]. To adjust the energy consumption to the available energy supply, an energy-oriented production planning system is required that uses existing energy flexibility potentials in the manufacturing systems [7]. Various surveys have presented theoretical energy flexibility potentials in different energy intensive industries [5]. In consequence of the higher demand of energy flexible factories there is the task to establish a structured method to make more potentials technically and economically accessible[7].

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems
doi:10.1016/j.procir.2017.03.357

This publication proposes a method to increase the energy flexibility of manufacturing systems. It includes a module to create transparency of the energy demand, a module to break down the external requirements for energy flexibility and to identify the energy flexibility gap, a module to identify measures to increase the energy flexibility and finally, a module to rate the developed measures is presented.

2. Energy flexibility

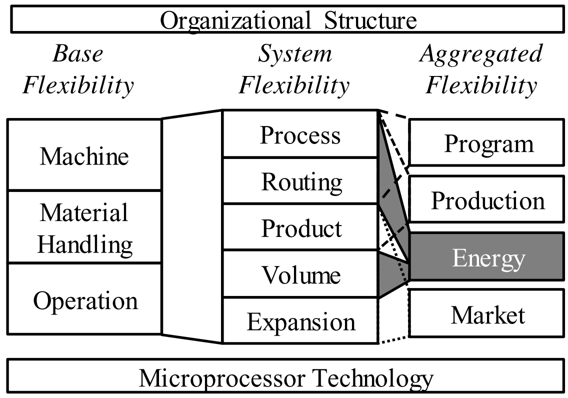
In the last years several surveys have discussed the energy flexibility of manufacturing systems [8–11]. To ensure a common understanding of energy flexibility, the following chapter outlines definitions, classifications and the dimensions for an energy flexible manufacturing system. Finally, on this basis, the requirements of a method to increase the energy flexibility are presented in this section.

2.1. Definition and Classification

The term flexibility is used in several ways and sometimes also as synonym for longer system changes. In general terms, flexibility describes the ability of a system to adapt to changes in- or outside the manufacturing system. In regard to the classification of Wiendahl et al. [12], the structure of the manufacturing system may change but new elements are not included or removed. Based on this definition energy flexibility describes the ability of a system to adapt its energy demand in consequence of a changed energy supply [7]. Pursuant to the survey and classification the energy flexibility can be integrated as an input oriented, aggregated flexibility. Hence, it is on the same level as the market, program and production flexibility. In contrast, the energy flexibility adjusts to volatile supply and not a volatile demand. Thus, it is an input oriented kind of flexibility.

Based on the hierarchy of flexibility presented by Sethi & Sethi [13] the energy flexibility can be structured in a similar way. The energy flexibility also depends, like the market or production flexibility, on to the volume, the route and the product flexibility [14]. Because each of them is influencing organizational the energy demand of the manufacturing system, they are called system flexibility. Similar to the flexibility properties, the energy demand is a feature of the plant and the process and describes, hence, the basis of energy flexibility. Consequently, the energy flexibility can be described as the forth aggregated flexibility based on the structure of Sethi & Sethi [13] (see Figure 1)

By explaining the definition and the classification of energy flexibility the central dimensions are highlighted. In relation to energy flexibility the range is described by the two dimensions power change and time according to the manufacturing system or station state. The activation or deactivation of different states is defined as speed time. The third dimension of energy flexibility is the action ability that includes the costs to use energy flexibility measures but also the system complexity, and controllability to adapt the manufacturing system to the energy supply. The three dimensions depend on one another. Therefore, to increase the energy flexibility each of these dimensions have to be analysed and solutions have to be developed under this premise.



2.2. Figure 1: Classification of flexibility in manufacturing systems (based on [13])System Engineering

For a focused and appropriate design of complex systems, the systems engineering with its own mindsets and principals has been established. In this approach the systems theory divides a system in several subsystems with elements and relations. Haberfellner et al. [15] have structured the systems engineering approach into the following four steps.

In the beginning the system is modelled with its elements and relations to build up transparency of the system, its boundaries, elements and relations. The second step is to determine the aims surrounded by the question “What is to be achieved or rather avoided?” [15]. With the previous steps in mind, a synthesis has to be made and solutions have to be identified which are finally evaluated for the decision-making. During the system engineering the following two principals are always part of the process:

- from rough to detail
- thinking in alternatives

Keeping in mind the systems engineering approach with the focus onto the energy flexibility the next section shows the requirements of an approach to increase energy flexibility.

2.3 Requirements for factory planning

An energy flexible factory contains certain flexibility potentials to vary the energy demand and can be seen as a structural feature of the manufacturing system. The energy flexibility measures, at a certain point of time, are part of the amount of flexibility potentials because some of them are not available or do not have the required impact. Consequently, energy flexibility potentials have to be designed in a structured way to avoid unnecessary investments and to guarantee an energy oriented production planning and control. Therefore, the systems engineering philosophy has been used