Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 72 (2018) 826–831

www.elsevier.com/locate/procedia

51st CIRP Conference on Manufacturing Systems

IT Platform for Energy Demand Synchronization Among Manufacturing Companies

Daniel Schel, Dennis Bauer*, Flavio Gonzalez Vazquez, Fabian Schulz, Thomas Bauernhansl

Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Nobelstr. 12, 70569 Stuttgart, Germany

* Corresponding author. Tel.: +49 711 970 1355. *E-mail address:* dennis.bauer@ipa.fraunhofer.de

Abstract

Demand Response as a propagated solution to address the challenges of an increasingly volatile energy supply due to renewable energies requires sufficient IT solutions to synchronize manufacturing companies with energy markets. To support especially small and medium-sized enterprises in mastering this challenge, an approach for an appropriate IT infrastructure and a modular, service-oriented and secure cloud platform have been developed. Services on the platform allow for aggregation, analysis and optimization of production data as well as energy-synchronized control of production processes. In order to allow for a flexible and uniform access to energy consumption data in a landscape of heterogeneous and legacy production controls systems, a smart connector has been developed to enable a modular approach to energy and production data acquisition. Both, platform and smart connector combined allow manufacturing companies for a smart and energy-flexible production implementation.

Peer-review under responsibility of the scientific committee of the 51st CIRP Conference on Manufacturing Systems.

Keywords: Digital Manufacturing System; Energy Efficiency; Flexibility

1. Introduction

By the end of 2016, 176 countries had renewable energy targets in place and more than 100 countries have joined the Paris Agreement [1]. German government is aiming at a 50 percent share for renewable energies of the gross power consumption by 2030 while reducing the number of conventional power plants [2]. Therefore, the energy system is facing the challenge of integrating a continuously growing share of fluctuating power generation by renewable energy sources. At the same time, the power supply is intended to always remain stable and affordable. The growing volatile energy supply is forcing the need to keep a balanced energy supply and demand. The so far existing paradigm of "supply follows consume" disappears and the system needs to be more flexible [3].

While measures like the expansion of the power grid imply high costs and low social acceptance, the development of a smart grid including automated Demand Response (DR) offers the chance of addressing the energy turnaround in a socially accepted and cost efficient way [4]. In 2016 the manufacturing sector, especially energy-intensive branches, are responsible for 44 percent of the total net power demand in Germany [5]. This shows the huge potential for applying automated DR, i.e. load shedding, load growth and load shifting, to the industry [4,6]. To realize a fully automated DR, new concepts and information technologies are needed.

The concept of an energy synchronization platform has been proposed to achieve a more flexible design of the energy system [7]. While the energy synchronization platform itself is a holistic concept of requirements, general conditions and design, it consists of two logical platforms – the market-side platform and the company-side platform (CoP). Both platforms are integrated via a service-oriented connecting interface (Fig. 1). Each platform encapsulates the knowledge, methods and technologies of its specific domain to maintain a safe state without affecting the operation and performance of the overall system. The goal of the energy synchronization platform is for the industry to actively participate in the energy market by a more accurate and faster demand planning (consumer role) as

2212-8271 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the 51st CIRP Conference on Manufacturing Systems.
10.1016/j.procir.2018.03.237

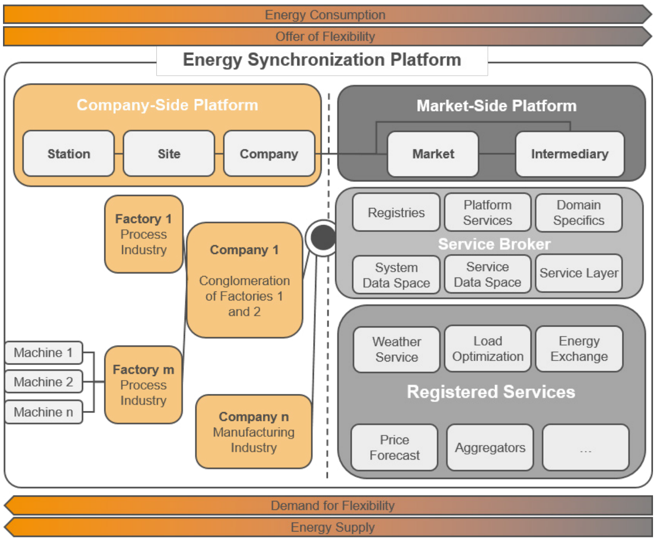

Fig. 1 Concept of the energy synchronization platform

well as by providing energy flexibility potential (supplier role). These roles can be flexibly switched depending on external factors (e.g. grid stability) and internal factors (e.g. production schedule).

This paper presents an approach for the CoP to enable the active participation in the energy market via a single interface to the market-side platform. Therefore, it will not be necessary to connect to multiple market partners to realize the potentials through automated DR.

2. The Proposed Concept

The CoP represents the modular, service-oriented, secure and externally encapsulated information and communication technology system within a company. It includes acquisition, aggregation, analysis and optimization of process and production data on one hand, and energy-synchronized control of the systems, plants and components on the other hand. Hence, it enables energy-flexible behavior in the future electricity system. In order to fulfill this task, the CoP must meet the following minimum requirements.

In order to acquire data from systems and components on the shop floor and to control these systems and components, a connection to the CoP is necessary. It cannot be assumed that this connectivity is already part of existing systems and components, thus a corresponding generic or configurable adapter is required.

Additionally, services can intervene in production processes through this adapter, which causes the demand for guaranteed response times. The processing of data at all granularity levels cannot be guaranteed by limiting the network bandwidth. Therefore, the execution of services such as data pre-compaction for aggregation or algorithms for pre-processing must take place close to the process.

All connected devices or adapters must be managed in the CoP to be able to manage and provide their energy and operating data. This information should be accessible by services on the CoP to enable the aggregation, analysis and optimization of process and production data.

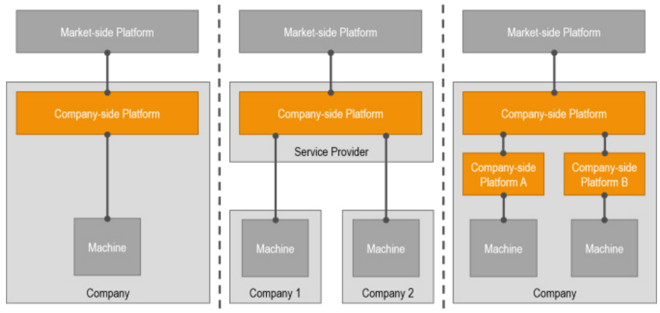

Fig. 2 Deployment models of the company-side platform

The CoP must also provide the ability to develop, distribute and operate such services in order to ensure easy creation, reusability and flexible deployment of these services [8]. In this context, developing new services based on already existing ones would be the ideal option for reusability and sustainability.

The coupling of CoP with the market-side platform and the exchange of data between them requires an interface between the two platforms. The CoPs have to identify themselves to the market-side platform, to offer energy flexibility and receive price forecasts for usage in optimization services.

Consequently, different roles in the CoP's ecosystem can be derived. There are "Independent Service Vendors (ISV)" who develop and/or market services on the CoP. These services can be based on ISVs own services and/or existing services of other ISVs. Manufacturing companies in their "End Customer" role are able to use services from various ISVs to integrate these services into a solution providing appropriate support for their business processes. The "Platform Operator" role ensures the operation of the CoP for the provision of services, as well as the basic functionalities for service automation and orchestration, in order to enable a fast and efficient provision of services. It also has to maintain the integrity of the platform from a governance point of view and to ensure the functionality and security of the services. In addition, it serves as the first point of contact for end customers and ISVs [9].

Different deployment models are required to make the platform flexible enough to be used by companies from different industries and of different sizes. These deployment models can be grouped into the following models (Fig. 2, left to right):

- Standard Deployment - Stand-alone or private CoP deployment consists of a single instance of the CoP that is operated and used by a single company.
- Service Provider Deployment - Public instance of the CoP operated by a service provider that can be used by several companies. This approach is aimed at small and medium-sized enterprises (SMEs) that do not or cannot operate their own infrastructure.
- Enterprise Deployment - Cascading or hierarchical deployment of multiple CoPs with the aim of providing services at different levels of the company. With this deployment, already established structures from the energy sector can be mapped, e.g. aggregators.

3. Implementation

Based on the requirements and roles described in the previous section, the CoP can be seen as a combination of the following service categories:

- Infrastructure as a Service (IaaS) from the platform operator's point of view
- Platform as a Service (PaaS) from the ISV's point of view
- Software as a Service (SaaS) from the end customer's point of view

IaaS, PaaS and SaaS are layers that are built on one another, which is also intended for the implementation of the CoP. In order to ensure parallel development, as well as maintainability, adaptability and extensibility, the platform itself should be based on a modular and service-oriented architecture. The approach of the Self-contained System is adopted, which is comparable to the microservice architecture pattern. An essential difference lies in the granularity of the services. Self-contained systems are defined as functional units, which are encapsulated as independent modules. They have all layers of persistence, business logic and presentation. The communication between these modules takes place via well-defined interfaces, which prevents the emergence of large, monolithic systems and thus ensures extensibility, changeability and maintainability [10]. In order to avoid an exponentially increasing number of direct connections between the modules in the case of loosely coupled, lightweight communication between the modules, it is advisable to use an integration layer between the modules. This integration layer is represented by the Manufacturing Service Bus [8]. The architecture of the CoP is designed according to this approach in the background (Fig. 3). The focus here is on the PaaS layer, because it acts as an enabler for the SaaS layer. The IaaS layer is not considered, as there are already established solutions on the market, e.g. OpenStack for VMs or Kubernetes for containers. Based on such universal packaging formats and using a corresponding abstraction layer at the PaaS level, the actually used IaaS technology can be transparently replaced. The following sections describe the individual components in more detail: service development, distribution and operation scope as the platform's basics; the Manufacturing Service Bus as an integration layer; the smart connector as an interface to manufacturing processes; and finally, services built on the CoP for realizing automated DR.

3.1. Service development, distribution and operation scope

The company portal, platform services and IaaS interface components form the functionality of the platform to provide, manage and operate applications as services on the platform, some of which are subdivided into sub-modules.

The company portal is a web-based frontend that provides all required functions and interfaces to the respective user groups. These are connected via the RESTful based interfaces of the underlying modules.

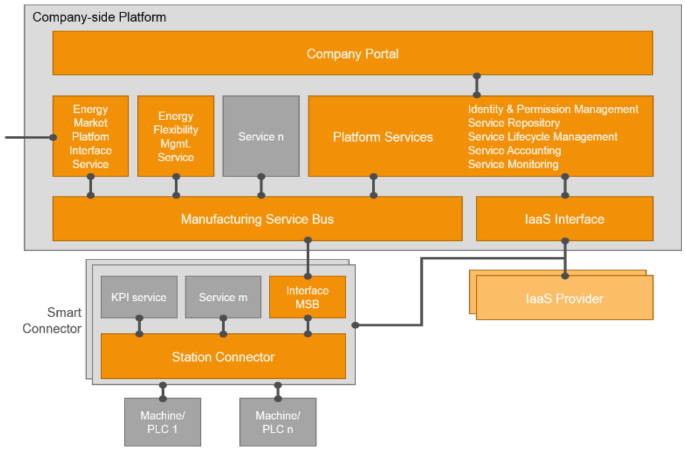

Fig. 3 Component diagram of the company-side platform

The platform services are represented by several modules, which have been divided according to their functional scope as follows:

- Identity & Permission Management
- Service Repository
- Service Lifecycle Management
- Service Accounting
- Service Monitoring

Identity & permission management is the core component for managing users and organizations as well as the associated roles and rights model. Users are assigned to roles and have the authorization to access services of an organization. This does not yet specify the rights a user has within an organization's service. The required roles, authorizations and user assignments are managed by administrators of the respective organization.

The **service repository** manages the available services. In addition to marketing and commercial aspects, the technical description for an automated instantiation and dependency management is also stored here. All these aspects can be summarized under the term service template. The onboarding process of new service templates also needs to be supported by the service repository.

If a service is instantiated from the service repository, provisioning of the service is taken over by **service lifecycle management**. This manages the lifecycle of a service instance, which comprises the following steps:

- The described provisioning of services.
- Update or change management of a service
- De-provisioning or cancelling a service
- Delete or permanently remove a service and the associated data.

Service accounting ensures that services can be billed. This process involves four steps: pricing, service metering, charging back and billing. When creating a service template in the service repository, a corresponding price model for it can be defined in service accounting. If the service is now instantiated, a corresponding service metering is triggered for the use of this service in service accounting. The measured usage and the selected price model are brought together in the chargeback step and billed to the corresponding beneficiaries or debtors. In the billing step, monthly invoices are then generated for end customers, ISVs and platform operators.

The task of **service monitoring** is to monitor the fulfilment of the agreed service level agreement (SLA) with regard to the availability and the quality of service. In addition to these aspects, it is important to be able to quickly recognize error patterns in services. This allows for an appropriate reaction to assure the SLA.

As mentioned above, the IaaS interface is a standardized interface to the infrastructure layer. This means that it can be exchanged as required or several different IaaS providers can be connected.

3.2. Manufacturing Service Bus

The Manufacturing Service Bus (MSB) represents the middleware for service orchestration, as well as the platform gateway for connecting the physical objects, as Industrial Internet of Things, to the CoP (Fig. 4). The MSB offers management of connected sensors, actuators and existing software services, so-called smart objects and applications. These can be connected either directly or via smart connectors (cf. section 3.3). All input and output information needed for the integration of these smart objects and applications is managed by the MSB. Hence, the focus of the MSB is on reducing the integration effort between smart objects and applications as well as accelerating their integration. For this purpose, the MSB works with a combination of three well-known integration and communication patterns: publish-subscribe, workflow-based integration, event- and message-driven communication.

The basis assumption for the need of an integration support is the existence of different information models and communication standards. To harmonize the information models of the participating smart objects and applications, which can be fundamentally different in their semantics, the MSB uses a universal self-description of the service interfaces. This allows for a translation between different information models by the MSB. To support different communication standards, the MSB offers several interfaces, e.g. REST, Web-Socket, OPC-UA, MQTT [11]. The interfaces are extended by the smart connector, described in the following section.

3.3. Smart Connector

The smart connector (SC) serves the CoP by making programmable logic controllers (PLC) and their data available to the MSB as smart objects. Additionally, the SC translates the signals coming from services on the CoP into commands, which the control equipment can understand through a unified interface. This results in the ability to read and write data from and to any PLC without having to implement different interfaces at the MSB, and consequently centralizing and modularizing the support for arbitrary equipment.

The SC comes with connection modules supporting Beckhoff TwinCAT ADS [12], Siemens STEP7 protocol [13] and OPC-UA [14] compatible devices, among others. The SC can be extended by creating custom connection modules. This is useful for connecting to proprietary protocols or to directly integrate equipment or smart sensors not connected to a PLC. By making the interface to the SC as unified and open as possible, the SC can be implemented into many software solutions other than just the CoP. Thus, companies which use the SC for the CoP, can use it in their own systems as long as there is a secure connection to the SC setup.

Software solutions like the CoP are able to subscribe to a set of variables from multiple PLCs. The SC implements two different types of subscriptions which define the way the changes of the set of variables are communicated to the CoP: continuous updates on a predefined fixed interval, or notifications when any of the variables in the set changes.

Additionally, just like the CoP itself, the SC is able to run custom user-written services on its own to aggregate or pre-process data close to manufacturing processes (Fig. 3). An example of this ability to pre-process data is to pre-compact variables into defined key performance indicators (KPI), e.g. for the flexibility scope as described in [15]. The KPIs calculation is defined in metadata documents, which are stored in the SC. That metadata can additionally be used to describe the variables available in all PLCs of the plant, which the SC is meant to serve (in this context, a plant is a collection of PLCs of one or more machines). When the metadata is available, the SC will try to connect to all specified PLCs and will provide the KPIs as part of the defined plant.

Various energy flexibility measures can be derived from the process data. The flexibility scope approach, consisting of one or multiple energy flexibility measures, is chosen to describe this holistic approach for a system. A set of calculated KPIs is used to describe a number of possible energy flexibility measures in form of a flexibility scope. This flexibility scope is transmitted from the SC to the CoP using the MSB interface.

The integration with the MSB is also implemented as a service running inside the SC. The SC registers itself to the MSB upon service instantiation. The service then handles the communication of the flexibility scopes and the incoming actions to control the plant, the subscription data, computed KPIs as well as changes to the plant configuration (connected PLCs, variable metadata, etc.).

The SC can be installed directly into a PLC in case it is Windows- or Linux-based. Alternatively, it can be installed on a separate computer which then is connected to one or multiple PLCs.

3.4. Energy Flexibility Management Service

The flexibility scopes of the plants transmitted by the SCs are transferred via MSB to the energy flexibility management service (EFMS) on the CoP. This service is used to aggregate and manage all the flexibility scopes of a company and thus provides an overall view. Besides the SC, this is the second level for aggregation of flexibility scopes.

The decision which flexibility scopes are offered on the market can either be made manually or automatically. A manual decision can be executed for example by the company's energy manager using a graphical user interface to the EFMS. An automated decision can be made by optimization services (section 3.5) depending on certain input values, such as

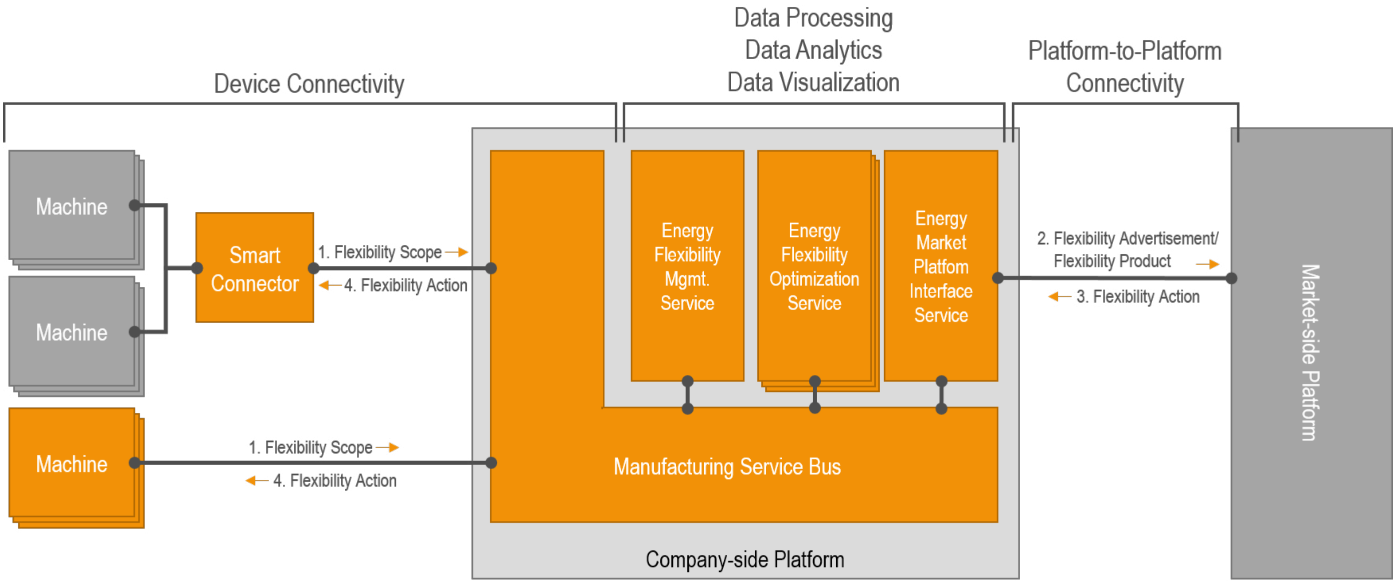

Fig. 4 Platform and component interaction

predicted power price. The decision is then communicated back to the EFMS by an application programming interface (API). Finally, the chosen flexibility scopes are transmitted to the energy market platform interface service.

In addition, the EFMS also offers the possibility to combine or split individual flexibility scopes to create new or virtual flexibility scopes. This makes it possible to vary flexibility scopes at a later stage, depending on market requirements and abstracted from practical implementation. In order to fulfill this task, the EFMS must be able to manage the dependencies between actual and virtually generated flexibility scopes.

3.5. Energy Flexibility Optimization Services

This group of services fulfills the task of performing specific analysis and optimization based on the existing flexibility scopes. They can be different depending on the branch, manufacturing process, machinery or management strategy and may require different input values. For this reason, individual optimization services are necessary that can be used as needed. As a result of such an optimization, a new virtual flexibility scope is created which is also adopted by the EFMS for further offering on the market. However, the execution is subject to the respective optimization service when triggered by the EFMS.

3.6. Energy Market Platform Interface Service

The flexible scopes approved by the EFMS need to be placed on the energy markets. This is achieved by using the energy market platform interface service (EMPIS) to access the market-side platform. The EPMIS allows for a unified access to various markets via a single interface.

Flexibility scopes are offered on the market as energy flexibility advertisements. They can be found and requested by market participants. All relevant data of the energy flexibility product will then be transmitted to the market participant and can be retrieved in due course.

When a request by a market participant is made, a flexibility action is sent to the EMPIS on the CoP. By assigning this flexibility action to the corresponding flexibility scope, the respective SC or energy flexibility optimization service to realize the requested flexibility action can be determined by the EFMS.

4. Application and Benefits

A possible application for automated DR by the proposed platform is a combined manufacturing process of a heating rod, a heat reservoir and a heat consumer. The heat consumer can either be heated by the heating rod or – as an energy flexibility measure – by the heat reservoir, serving as a buffer, without affecting the manufacturing process of the heat consumer. The combined process and its inherent flexibility scope can be characterized by certain KPIs [15], such as power gradation, capacity of the buffer, reaction duration or minimum holding duration. An application scenario like this can be found in model factories [16] as well as in industry [17].

Without the concept of the CoP there is no unified access to various markets and all data and information handling has to be done manually. The concept of the CoP allows for automated integration of flexibility scopes and data handling with the markets.

In the described application most likely each component will be equipped with a PLC from a different vendor, e.g. the heating rod with a PLC by Beckhoff, the heat reservoir by Bosch Rexroth and the heat consumer by Siemens. The SC connects vendor-independently to all three different PLCs and supports defining the process-inherent flexibility scope characterized by the mentioned KPIs. All flexibility scopes – in this application just the one to use the heat reservoir as buffer and therefore power down the heating rod – are communicated to the EFMS (Fig. 4, step 1).

If multiple flexibility scopes are transmitted, either from a single or multiple SCs, the EFMS is able to aggregate them within the company in order to achieve markets' minimum criteria [3]. A decision maker, either human or automated, then choses, which flexibility scope or which aggregation of flexibility scopes should be put on the market. All data and information handling for this energy flexibility trading is done by the EMPIS (Fig. 4, step 2). This allows for a unified access to various markets such as EPEX Spot or Regelleistung.net.

Once a trade is agreed on, a flexibility action is sent to the EMPIS on the CoP (Fig. 4, step 3). The EFMS then blocks this flexibility to prevent double marketing and triggers realization by the respective SC. Within the SC, the flexibility scope is translated into control signals for the process to be executed by the PLCs – in the described application to power down the heating rod for a given time and meanwhile supply the heat consumer by the heat reservoir (Fig. 4, step 4).

Companies benefit from this approach by fully integrated production equipment using SC and MSB. Moreover, this allows for automated data and information flows as well as handling even for process combinations such as the described application. Media discontinuities are prevented. The CoP as an integrated part of the energy synchronization platform establishes the possibility for companies to use a unified interface to various energy markets. Thereby, the platform speeds up the process of energy flexibility trading and reduces its cost.

5. Conclusion and Outlook

The paper presents a concept for an IT platform to synchronize energy demand with a continuously growing volatile energy supply by applying automated DR. First, minimum requirements for such a platform have been derived. Second, an implementation based on these requirements has been detailed. Major components of the platform are MSB, SC, EFMS and EMPIS. Based on the requirements and the implementation an application example, namely the energy flexibility resulting from a combination of a heating rod, a heat reservoir and a heat consumer, shows the expected benefits of the proposed platform.

However, the benefits need to be validated by applying the platform in a real environment. Additionally, methods and mechanics for the aggregation of flexibility scopes have to be detailed for the EFMS. Furthermore, services for the mentioned analysis and optimization of production and energy data have to be designed and developed.

Acknowledgements

The authors gratefully acknowledge the financial support of the German Federal Ministry of Education and Research (BMBF) and the project supervision of the Project Management Jülich (PtJ) for the project „SynErgie“. The authors are responsible for the contents of this publication.

References

[1] REN21. *Renewables 2017: Global Status Report*. http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf (accessed on 26.10.2017).

[2] Umweltbundesamt. *Klimaschutzziele Deutschlands*. https://www.umweltbundesamt.de/daten/klimawandel/klimaschutzziele-deutschlands (accessed on 27.10.2017).

[3] Bertsch J, Fridgen G, Sachs T, Schöpf M, Schweter H, Sitzmann A (2017) Ausgangsbedingungen für die Vermarktung von Nachfrageflexibilität: Status-Quo-Analyse und Metastudie. *Bayreuther Arbeitspapiere zur Wirtschaftsinformatik*(63).

[4] Kohler S, Agricola AC, Seidl H. *dena Netzstudie II: Integration erneuerbarer Energien in die deutsche Stromversorgung im Zeitraum 2015 - 2020 mit Ausblick 2025*. https://www.dena.de/fileadmin/user_upload/Download/Dokumente/Studien___Umfragen/Endbericht_dena-Netzstudie_II.PDF (accessed on 26.10.2017).

[5] Umweltbundesamt. *Stromverbrauch*. https://www.umweltbundesamt.de/daten/energiebereitstellung-verbrauch/stromverbrauch (accessed on 26.10.2017).

[6] Palensky P, Dietrich D (2011) Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads. *IEEE Trans. Ind. Inf.* 7(3):381–8.

[7] Bauer D, Abele E, Ahrens R, Bauernhansl T, Fridgen G, Jarke M, Keller F, Keller R, Pullmann J, Reiners R, Reinhart G, Schel D, Schöpf M, Schraml P, Simon P (2017) Flexible IT-platform to Synchronize Energy Demands with Volatile Markets. *Procedia CIRP* 63:318–23.

[8] Götz B, Schel D, Bauer D, Henkel C, Einberger P, Bauernhansl T (2018) Challenges of production microservices. *Procedia CIRP*(67):167–172.

[9] Holtewert P, Wutzke R, Seidelmann J, Bauernhansl T (2013) Virtual Fort Knox Federative, Secure and Cloud-based Platform for Manufacturing. *Procedia CIRP* 7:527–32.

[10] innoQ. *Self-Contained Systems - Assembling Software from Independent Systems*. http://scs-architecture.org/ (accessed on 03.04.2017).

[11] Schel D, Henkel C, Stock D, Seidelmann J (2018) Manufacturing Service Bus: an Implementation. *Procedia CIRP*(67):179–184.

[12] Beckhoff. *Einführung ADS*. https://infosys.beckhoff.com/index.php?content=./content/1031/tcadscommon/html/tcadscommon_introads.htm&id (accessed on 29.11.2017).

[13] Berger H (2017) *Automating with SIMATIC S7-1500: Configuring, Programming and Testing with STEP 7 Professional.* 2nd ed. Publicis MCD Werbeagentur GmbH, Newark.

[14] Damm M, Leitner S-H, Mahnke W (2009) *OPC Unified Architecture*. Springer, Berlin, Heidelberg.

[15] Weber T, Schel D, Schott P, Bauer D, Pullmann J, Abele E, Bauernhansl T, Fridgen G, Jarke M (2018) Generic Data Model For Describing Real-Time Data-Supported Power Flexibility. *SmartER Europe, 8th February 2018, Essen, Germany*:15p.

[16] Abele E, Bauerdick CJH, Strobel N, Panten N (2016) ETA Learning Factory: A Holistic Concept for Teaching Energy Efficiency in Production. *Procedia CIRP* 54:83–8.

[17] Trimet Aluminium. *Die Aluminiumhütte als „Virtuelle Batterie“*. http://www.trimet.eu/de/ueber_trimet/energiewende/virtuelle-batterie (accessed on 21.02.2018).