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Flexible IT-platform to Synchronize Energy Demands with Volatile Markets

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Abstract

Based on the goal of exiting nuclear and fossil energies within the electricity generation, the percentage of renewable energies in the energy mix rises. Due to renewable energies' dependence on natural resources like sun or wind this development leads to a volatile energy supply on the markets. To satisfy their customers' needs even with a volatile energy supply, especially companies of the manufacturing sector need to consider this development. Production processes need to be developed further to be more energy efficient and to be adaptable in their energy demand to volatile supply. This includes being operable on various power levels or with different kinds of energy such as electricity or gas. Energy-flexible production processes need to be supported by flexible IT solutions. While there are already solutions for demand-side-management on the company side as well as on the market side, there are no holistic solutions yet, allowing for integration regardless of company or market boundaries. Therefore, this paper presents the concept of a service-oriented architecture for a flexible IT-platform to synchronize energy demands with volatile markets. A holistic approach allows for integration of companies as well as energy markets and enables an automated and efficient exploitation of demand response potentials.

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Keywords: Digital Manufacturing System; Energy efficiency; Flexibility

1. Introduction

The electricity system in Germany 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 remain stable and affordable. The growing volatility in combination with the reduction of conventional power plants causes the necessity to change the power market and the energy procurement to achieve a balanced supply and demand. One possible solution is the flexibilization of demand. These days, industrial processes (and especially big systems in energy-intensive branches) in Germany have a 44% share of the total net electricity demand and 29% of the total heat demand [1]. This shows the huge potential of the industry with regards to the contribution in solving the upcoming challenges. While other measures like the adaption and expansion of the electricity grid imply high costs and low social acceptance, the so called Demand-Side-Management (DSM) offers the chance of a cost efficient and socially accepted energy turnaround. Therefore, the flexibilization of the electric power demand (procurement and positive/negative load fetching) in the short and medium terms is necessary [2–4]. The potential which can be realized by industrial DSM is separated by industries as illustrated in [5]. Still, it is also stated, that more technology research needs to be done to successfully apply DSM. To synchronize the

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power demand and supply a software solution is needed to exchange information between all participants in the electricity market. As a precondition, energy suppliers as well as energy consumers need to establish suitable IT solutions as a major part of their business strategies [6].

Information and communications technologies (ICT) are key enabler for realizing the vision of a fully digitalized and networked world. Besides connecting all participants in the electricity market via smart grids, this also includes smart mobility, smart logistics and smart products which are produced in smart factories [7]. It is estimated, that in 2020 there will be 20.8 billion networked smart objects in the Internet of Things (IoT) generating 44 ZB new data annually [8, 9]. Smart grid is considered as one of the main IoT applications and the proposed approach to overcome the limitations of the current energy grid [10]. To handle and analyze these amounts of data to synchronize smart grids with smart factories a new generation of IT-platforms as well as data analytics technologies are necessary [11, 12]. Therefore, this paper presents an approach for a flexible IT-platform to synchronize energy demands with volatile markets.

2. Energy Synchronization Platform

2.1. Concept

The Energy Synchronization Platform presented here bridges the gap between the increasingly dynamic energy market and enhanced, energy-aware manufacturing processes. It provides the technological backbone for real-time synchronization of flexible production and volatile energy supply. The platform enables the industry to actively participate in the energy market, contributing to a more accurate demand scheduling on the one side (consumer role) and providing an unprecedented flexibility and demand reduction potential on the other side (supplier role). Dependent on the current circumstances the roles of being an energy consumer or an energy supplier can be flexibly changed. Additionally, the emerging role of electricity aggregators trading flexibility potentials increases the complexity and dynamism of the energy market. In order to cope with this complex ecosystem the Energy Synchronization Platform can be decomposed into two logical platform types – the Market-side Platform (MaP) and a Company-side Platform (CoP), interconnected via a lightweight service-oriented Connecting Interface (CnI) as depicted in Fig. 1. Each of the platforms encapsulates its particular domain, technologies and methods, maintaining a safe state without affecting the operation and performance of the overall system. The main goal of the composite platform is to efficiently link the identified load shifting potential of the companies to the future requirements of the energy sector. Initial conceptualization of the interfaces, protocols and data models that integrate the two platforms takes into account related scientific and industrial initiatives. Among others, the Universal Smart Energy Framework (USEF) proposes a modular design for flexible smart energy systems, including the definition of flexibility value chains, interaction models, programmatic interfaces and message formats [13]. Likewise the work on Energy Flexibility Interface (EFI) explicitly expresses energy flexibility capabilities of smart appliances and is relevant here in regard to the definition of a generic, versatile data format allowing for modelling and automated trading of flexibility between the market-side and company-side platforms [14]. Therefore, the usage of semantic modeling technologies has to be evaluated to create an ontology for a truly re-usable, extensible and machine-readable flexibility model [15] .

In order to meet the key requirement of the platform to maintain a guaranteed performance and Quality of Service level, independent of the complexity, type and time-variability of production processes, an extensive effort will be put in the analysis and modelling of the relevant process characteristics, especially in regard to their energetic footprint. Therefore, an extensive, multidisciplinary requirement elicitation process will be set up in order to design the CnI and the information flows integrating both logical platform types.

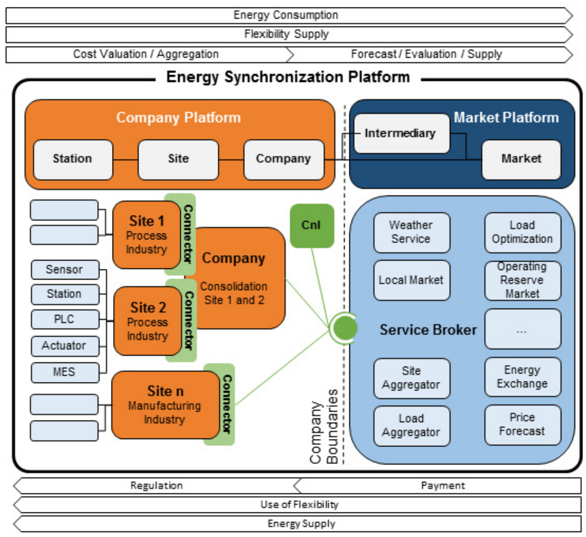

Fig. 1: Proposed architecture for the Energy Synchronization Platform

2.2. Market-side Platform

Companies seek for monetization of the provided amount of demand response [16, 17]. Without a monetary incentive, most companies won't put effort in participating in a demand response market. Furthermore, the market's need for demand response heavily depends on current power prices and balancing power prices, both are traded on exchanges. In contrast to existing platforms such as caterva or ETPA.nl, the MaP surrenders the value added to the participants of the platform and charges the connection of participants. It also aims at integrating all stakeholders and enables the information exchange via an extensible service-broker-architecture (SBA) based on a message broker [18], providing a fair and comprehensible market mechanism. Furthermore, this architecture pattern fosters the participants of the energy market to develop new innovative services. To do so, the SBA pattern provides a mechanism to dynamically register services and interfaces for their integration. Thus, a market place for innovative energy-related services arises, that fosters the competition between service providers. To attain the described goals, the following design principles are derived for the SBA:

- Standardization: In an SBA, standardized and open interfaces as well as communication protocols are required to enable vendor-independent communication between services and free competition between them.
- Competition among services: The goal of providing a free competition on the market of services results in a need for low market entry barriers without discrimination of competitors. A key challenge will therefore be, to prevent lock-in effects when a critical mass of participants uses one service.

For an implementation of the MaP according to these design principles, the following services are necessary:

- Service Broker: The Service Broker provides the connection among all services that participate in the market. It is therefore the core of the market. Services can be registered and requested by other services.
- Market Mechanism: To derive market acceptance, the MaP requires a fair and generic market mechanism, which also includes optimization. This mechanism takes information on products from power markets, as well as information on demand response potential from companies and computes a comprehensible and traceable result that aims at balancing supply and demand via a unified market model. Thus, the market mechanism demands an appropriate complexity to meet the markets requirements.
- Payment: Ensured payment from service requester to service provider is mandatory for a platform. However, providers may have various payment models, such as pay per use, subscription, or differential fees, which must be considered in the design of information exchange protocols.
- Power Market Services: It is mandatory, that existing Power Markets such as Power Exchanges and Balancing Power Exchanges are bidirectionally integrated into the market mechanism. Those markets generally provide APIs. Thus, demand response can directly be monetized and information on current power prices can be used in trade agents, forecast agents and the market mechanism.
- Trade Agents: The agents might be the major playground for competition among services. Trade agents are empowered by companies with a certain level of autonomy to make automatic decisions about energy purchases to a certain extent. Therefore, sophisticated algorithms and artificial intelligence approaches can be implemented.
- Companies: As companies are a major source for demand response [19], a frictionless integration into the SBA is mandatory to lower the market entry barrier. Thus, companies can monetize their demand response identified in the CoP.

Based on these elementary constituents, the MaP provides a first step towards an automatized and efficient exploitation of demand response potentials. To evaluate the platform's behavior, the project aims for a prototype. Subsequently, a spin-off might operate an advanced version of the MaP. In this version, to raise market efficiency in exploiting demand response potentials, further services that directly support new market players or facilitate the market access should be incorporated. Although the competition among services on one platform might be sufficient to overcome inefficiencies, there might co-exist more than one MaP. The initial version of the MaP is planned for the German market. However, if the concept of the MaP succeeds, there might be an expansion to other markets.

2.3. Company-side Platform

Nowadays, manufacturing IT is undergoing a fundamental change from the dissolving concept of the traditional automation pyramid to service-orientation, also indicated as Everything as a Service (XaaS) [11]. In favor of this service-orientation, software functionalities will be divided into services, decentralized offered by cyber-physical systems (CPS) and various cloud platforms. Due to this division of functionalities, communication between services based on open standards will become a key factor for success [20]. Nevertheless are existing approaches for such platforms often tailored around the products and services offered by the company's ecosystem and lack interoperability with other platform providers or integration of external systems [11]. The CoP, linking humans, equipment, CPS and software services within companies, shouldn't be designed in the form of a closed ecosystem, but quite on the contrary, it follows a federative approach. Usage of open communication standards is therefore key to prevent vendor lock-in effects. The architecture of the CoP, which can be instantiated for each company or site within the Energy Synchronization Platform, is inspired by the service-oriented platform architecture proposed in [11] and depicted in Fig. 2. The CoP can be operated in the form of a private, hybrid or public cloud, depending on specific company requirements as well as on the operator concept [21].

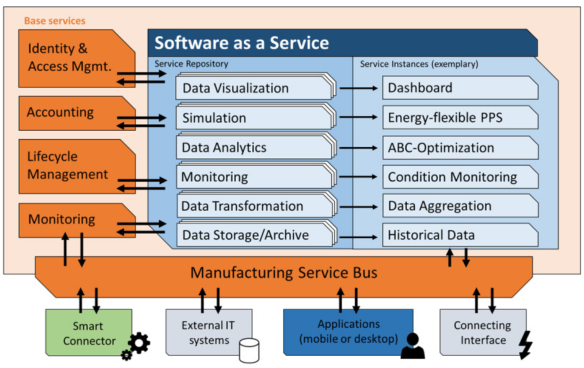

Fig. 2: Proposed architecture for the CoP

- Manufacturing Service Bus: On the factory layer of the platform [11, 22], all equipment, sensors, actors and CPS are integrated via a Manufacturing Service Bus (MSB) which is therefore the core component of the CoP. Integration is realized by offering open interfaces supporting the currently established industrial standards (e.g. OPC UA and ROS) and protocols (e.g. WebSocket, REST and MQTT). Besides the factory layer, all software services can be integrated into the MSB using these protocols. Bidirectional data and information flows are thereby controlled and executed by the MSB.
- Smart Connector: The smart connector allows for vendor-independent integration of legacy hardware which is not capable of communicating with service platforms. Therefore, the CoP adapts to current production equipment rather than requesting new equipment.
- Services: Independent service vendors (ISV) are able to offer their services on the CoP and users are able to instantiate and orchestrate services according to their needs in order to flexibly adapt to changing circumstances. As defined in [11], these services can range from back-end services, providing defined, clearly delineated features to front-end services, which are a combination of one or more back-end services with a user interface.
- Connecting interface: The CnI itself is a base service, establishing an interface between MSB and the MaP. Therefore, each instance of a CoP can be connected to other CoPs as well as to one ore multiple MaPs, depending on the operator concept. Challenges of defining a semantic model and data exchanged by the CnI are described in chapter 2.1.

While integrated via the MSB, all services can vendor-independently interact with production equipment, CPS, other services, mobile devices as well as with data provided by the MaP using the CnI. Bidirectional information flows executed by the MSB do not only allow for monitoring, but far more importantly also allow for influencing production and data-driven production optimization based on information from the energy market.

2.4. Built-in Security

Multiple threats arise by synchronizing the electricity market directly with the energy demand of factories. The current design of the Energy Synchronization Platform separates the platform into CoP and MaP as well as the CnI connecting these two platforms. Each instance of the CoP is controlled by one company and might need to be connected to intercompany networks like a production and an office network. The MaP is controlled by a MaP provider who is either the market operator or a third party. It could be assumed that multiple companies connect their CoP to one MaP. But at the current development stage it is not decided if they are connecting to one ore multiple MaPs, which depends heavily on the operator concept of the MaP. The MaP is connected to outside services such as a weather service which might not be under the control of the MaP provider. In addition, activities on the electricity markets can have consequences for the power grid. Therefore, the threats and respective counter measures to circumvent them need to be evaluated for each part of the platform as well as for the power grid.

By allowing the CoP to communicate with the MaP, the company increases its attack surface. As the attack on a German steel mill [18] and the Stuxnet worm [19] show, this enables a direct influence over the production processes. Both cases have in common, that attackers gained access to production network by hacking into other company systems. Furthermore, the CoP could be used to infiltrate the office network of the company and could lead to information disclosure. Security by design is therefore necessary to take counter measures like layering or input validation into account when designing the CoP and CnI. An attacker who wants to gather information or aims to destroy process equipment requires a certain determination and knowledge of the target. Still, a Denial of Service (DoS) attack does not necessarily require such skills and can therefore be very effective, especially when there is no response plan.

While a successful DoS attack targeting a CoP only affects one company, a DoS attack on the MaP could affect all market participants. Since the income generated by the MaP is the reason for running the MaP, the MaP provider will have a greater incentive for developing a response plan. Additionally the MaP can probably be distributed more easily than a CoP, which then requires stronger DoS attacks to disrupt it. However, the complexity level of powerful Distributed Denial of Service (DDoS) attacks is becoming lower and lower, as it can be seen in the Dyn attack [23] or the Operation Payback [24]. It must also be considered that the outside services could be attacked and that the failure of one subsystem does not affect the whole MaP.

For the MaP it must be ensured that no participant will be able to manipulate the market in their favor. Again for the outside services this needs to be ensured as well, since these services might be used to predict and calculate price changes. [25] and [26] explore these attacks on electricity markets in greater depth and the German Federal Office for Information Security also considers this potential risk in the KRITIS-study [27], which lists energy trading as a critical infrastructure for the power grid. This means that attacks on the power grid by an advanced persistent threat, which might use the Energy Synchronization Platform to leverage heavy energy consumers for its attacks, also have to be considered.

3. Benefits of the proposed approach

The proposed research aims at identifying the key constituents to enable cross-sectorial energy-flexible production processes. With the CoP it defines a dedicated infrastructure to systematically measure, aggregate and share energy characteristics of production processes. This concept therefore leverages and transcends advanced metering infrastructure (AMI), automated demand response (ADR) and smart production approaches towards the creation of a trustful exchange platform of consumption forecasts and demand-response offers (flexibility) allowing for data-based integration and optimization. The MaP on the other hand provides a generalized access to and a bidirectional integration of markets for power and balancing power. It further defines a novel eco-system of services allowing for competitive trading and optimization of power and demand response potentials. Complemented by a thorough business modelling of roles, interactions and clearing processes it empowers industrial prosumers of any size to exploit their flexibility potential and to actively participate in the volatile energy markets of the future. The holistic approach of the Energy Synchronization Platform integrates instances of the CoP and MaP via an innovative service-oriented architecture enabling automated and efficient exploitation of demand response potentials. While many existing approaches focus on decentral solutions [25, 26], the concept of this platform examines both possible views – decentral and central solutions. Moreover, security is an essential and built-in part, which is indispensable for a broad acceptance among companies and energy market stakeholders.

4. Implementation

With the goal of proving the feasibility of the developed Energy Synchronization Platform, we chose a two-step implementation approach. Within the first step the platform will be implemented in a model production environment at a university site with the following advantages:

- Different testing and validation scenarios can be performed without affecting a running production.
- Companies from different industrial sectors can be simulated to ensure broad applicability.
- Changes to the software framework as well as the local ICT-infrastructure can be directly implemented without the necessity to involve external instances/resources.

Within the second step we plan to implement the platform for demonstrating purposes in a running production environment of one of the industrial project partners.

The first step will take place at the ETA-Factory, a learning factory at the campus of TU Darmstadt. The ETA-Factory is a research and demonstration facility for industrial energy efficiency and energy flexibility solutions [28]. It hosts a representative demonstrator process chain from the metal processing industry with turning, grinding, hardening and different cleaning processes. By integrating the thermal activated building shell, the building technology and the production machines in an intelligent thermal network, energy savings beyond single system optimization can be achieved [29]. Besides the thermal interconnection between the different factory subsystems, an ICT-infrastructure is established allowing to monitor connected devices continuously on every information layer of the model factory (compare to Fig. 3). On field level information from sensors, actuators and different metering systems occur. This data is collected on a control level and shared via the industrial communication protocol OPC UA. On the process control and management level, control level data is evaluated and used for different optimization measures, e.g. the determination of an energy optimal operating schedule for the heating, ventilation and air conditioning system passed back to control level. The company-side part of the Energy Synchronization Platform additionally connects to all information levels via OPC UA. This is not only to gather data, but also to influence the energetic behavior of the factory, e.g. triggered by the current situation within the power grid or price signals.

5. Conclusion and Outlook

The Energy Synchronization Platform summarizes the proposed holistic concept for a technological backbone for real-time synchronization of flexible production and volatile energy supply. Thereby, the platform enables the industry to actively participate in the energy market both in a consumer role as well as in a supplier role. In addition, data and communication security needs to be carefully considered to create confidence in market-side and company-side platforms. The flexible IT architecture of the Energy Synchronization

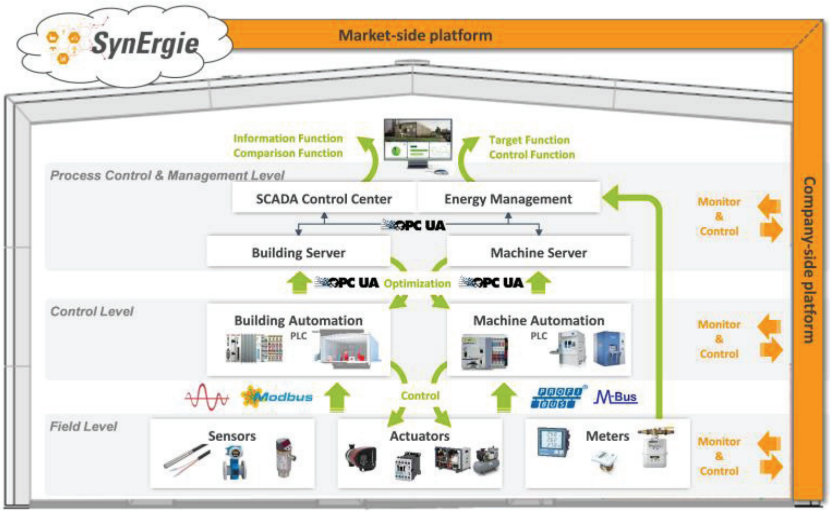

Fig. 3: Planned integration of the Energy Synchronization Platform within the ICT structure of the ETA-Factory

Platform will be a key technology to manage the shift to a continuously growing share of fluctuating power generation by renewable energy sources.

However, research on this topic has just started. The concept of the Energy Synchronization Platform needs to be enhanced and detailed architectures for CoP and MaP derived. Therefore, technical and economic questions have to be answered. On the technical side, one of the most important ones when talking about real-time is the response time of platform components. This implies the decision between processing raw or aggregated data, which applies for both, CoP and MaP. In addition, data and communication security will also be key for a wide acceptance and rapid adoption of the concept and therefore be in focus of further research. On the economic side, an operator concept for the Energy Synchronization Platform needs to be elaborated. This involves questions on who will operate the platform and if there will be one or multiple running instances of the platforms. While on the CoP side this is more a question of using private, hybrid or public clouds, for the MaP this includes a wide range of legal and regulatory issues when spreading multiple platform instances across different countries. Furthermore, usage of services within the whole Energey Synchronization Platform needs to be monitored for accounting purposes.

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