Flexible IT platform for synchronizing energy demands with volatile markets

Abstract: Abandoning fossil and nuclear energy sources in the long run and increasing amount of renewable energies in electricity production causes a more volatile power supply. Depending on external realities, renewable energy production emphasizes the need for measures to guarantee the necessary balance of demand and supply in the electricity system at all times. Energy intensive industry processes theoretically include high Demand Response potentials suitable to tackle this increasing supply volatility. Nevertheless, most companies do not operate their production in a flexible manner due to multiple reasons: among others, the companies lack know-how, technologies and a clear business case to introduce an additional level of flexibility into their production processes, they are concerned about possible impacts on their processes by varying the electricity demand and need assistance in exploiting their flexibility. Aside from fostering knowledge in industry companies, an IT-solution that supports companies to use their processes’ Demand Response potential has become necessary. Its concept must support companies in managing companies’ energy-flexible production processes and monetarize those potentials at flexibility markets. This paper presents a concept, which integrates both companies and energy markets. It enables automated trading of companies’ Demand Response potential on different flexibility markets.

Keywords: Platform, Smart Grid, Demand Response, Digitization, Industry 4.0

ACM CCS: Information systems → Information systems applications

1 Introduction

To realize the energy turnaround, the German Government is aiming at a 50 percent share for renewable energies of the gross power consumption by 2030 while reducing conventional power plants [1]. Due to the volatile nature of renewable energies the electricity system is facing the challenge of integrating a continuously growing share of fluctuating power generation. At the same time, energy-intensive industries require the power supply to always be stable, predictable and affordable. Combining the volatility of the supply and requirements of the demand, this development is forcing the need to keep a balanced energy supply and demand. The so far existing paradigm of supply follows consumption dissolves and the entire system, especially on the demand side, needs to become more flexible [2, 3].
On the consumer side, Demand Side Management includes all activities that lead to a change in the consumption of electricity. For example, efficiency increases or variable tariffs are part of Demand Side Management. This also includes Demand Response (DR), which is characterized on the one hand by a short-term use. On the other hand, the consumer reacts to a signal (e.g. a price signal) in order to deviate from the originally planned pattern of electricity use [4]. Therefore, the flexibilization of electric power demand (load shedding, load growth and load shifting) is necessary [3, 5–7]. These days, the industry sector and especially energy-intensive branches are responsible for 44 percent of the total net power demand in Germany [8]. This shows the huge leverage for applying DR to the industry [5].

However, several challenges occur when applying DR, which need to be tackled by further technology research. Among them are the lack of standards and information and communication technology (ICT) architectures required for automated DR in a smart grid [9, 10]. Among others, the integration of the smart factory with the smart grid is one of the key visions for a smart and connected world, described by Industry 4.0 [11]. Additionally, many distribution companies lack experience with ICT and the transition from the existing grid to a smart grid will rather be challenging [12]. Therefore, this paper presents a concept for a flexible IT platform to synchronize energy demands with a continuously growing volatile supply. On one hand, flexibility can be identified, aggregated, and managed within companies. On the other hand, access and participation in markets for power and flexibility will be facilitated.

2 Energy synchronization platform

Our research aims at identifying the key constituents and performing a cross-sectorial analysis of energy-flexible production processes in order to face the above-mentioned challenges. The concept of an Energy Synchronization Platform (ESP) is introduced as a holistic ICT-solution that is currently under development.

2.1 Concept

The ESP enables the industry to actively participate in energy markets by both a faster and more accurate scheduling (consumer role) and by offering DR potential (supplier role).

From a market point of view (e.g. energy exchanges), the ESP offers access to customers which have not been actively participating in energy trading so far. Additionally, connection and interaction with existing customers can be improved. Therefore, the ESP bridges the existing gap between the increasingly dynamic energy market and enhanced, energy-aware manufacturing processes and companies. Use Cases for commercializing DR potential of single loads as well as aggregated loads can be categorized in reactive and proactive Use Cases. While in proactive Use Cases the trigger for calling DR option is explicitly executed by companies (e.g. the company is planning to shut down a machine due to high energy prices), in reactive Use Cases the trigger is executed by an energy market (e.g. the company is committed to the signal of the net provider to shut down the machine due to a lack of energy in the grid).

The ESP provides the technical backbone for real-time synchronization of energy flexible production and volatile energy supply. Therefore, a holistic and integrated concept including data, information and energy flow between production equipment and energy markets is necessary. This concept of the ESP contains two logical platform types – the Market-side Platform (MaP) and the Company-side Platform (CoP) as depicted in Figure 1. Both platform types are interconnected via a service-oriented Connecting Interface (CnI) allowing the exchange of necessary data for automated DR. The decomposition into two logical platforms is required to encapsulate their specific domain knowledge, technologies and methods. At the same time, a safe state has to be maintained without affecting the operation and performance of the overall system. Besides the profitability of DR, this enhanced security is a key factor for acceptance of the ESP’s concept for both companies and energy market stakeholders.

Semantic modeling technologies [13] need to be used to create an ontology for a machine-processable, reusable and extensible data model for DR. In [14] an approach for a suitable data model has been described. Therefore, various existing models for energy flexibility have been analyzed with regards to the needs of manufacturing companies. Consequently, a state-dependent data model covering two types of flexibility has been derived. Namely these types are time-restricted and time independent power flexibility. The core requirement of the data model is that all forms of flexibility can be described as precisely as possible. In addition, the data model should enable aggregation and optimization of flexibility [14].

Within this framework, technical interfaces as well as boundary conditions for the integration and interaction of both logical platform types are defined. Consequently, the ESP is a concept while CoP and MaP are software solutions,
which will be implemented. The concept allows for many CoPs on which multiple services can be used. These CoPs are connected to one MaP. Several services can be used on this MaP, whereby several markets are also linked to the MaP that are suitable for the marketing of flexibility.

The CoPs will be operated by the companies themselves or by 3rd party service providers, depending on the requirements of a private or public cloud (cf. chapter 2.3). In contrast, the future operator of the MaP needs to be independent from all of ESP’s stakeholders to prevent conflicts of interest.

The interaction of the two platforms enables companies to market flexibility as follows. Flexible processes are captured with the help of the CoP and the services. The resulting DR potential can then be marketed on the MaP in a suitable market. Companies can use services on the MaP that determine, for example, the market that maximizes profits and the best time for flexibility. In the long term, the interaction between the two platforms and the services aims to automate the implementation of flexibility to a certain extent.

### 2.2 Market-side platform

There are two trends in current energy markets, which are relevant for future consideration. On one hand, the goal of companies is to monetize their offered quantity of DR [15, 16]. On the other hand, an increasing number of platforms provide the potential to monetize flexibility. Aside from existing platforms for balancing power [17], congestion management [18] or electricity exchanges [19], market providers and research projects identified the need for local market platforms [20].

However, the rising number of platforms decreases the market’s transparency and impedes measures for a balanced power grid, as power may not end up where absolutely necessary. In order to increase the markets’ transparency and to lower transaction costs for its participants, the project develops a MaP that integrates companies via the CoP wrapper (see chapter 2.3) with the already mentioned energy markets [21]. Thus, it is a key component of the ESP (see chapter 2.1). Furthermore, the MaP provides support services for its participants, ranging from weather forecasts to agents based on electricity markets. There will be a variety of competing services in order to subsequently enhance efficiency. In contrast to multiple CoPs, connected energy markets and offered services, there is only one MaP. This platform focuses on the efficient trading of flexibility and has intentionally no profit-oriented design.

#### Platform Architecture

The following components of the platform architecture represent the aforementioned objectives and realize the necessary functionalities of the MaP (see Figure 2):

- **Portal**: The portal enables access to the web-based MaP. It provides a homogeneous, integrated frontend for any kind of interactions with standard and 3rd party services to the MaP participants.
- **Service Broker**: The core of the market side platform is the service broker [22] which connects all CoPs with the different energy market places. The service broker interconnects all services that participate in the market. Providers can register their services, providing their offering to companies as well as other services. In order to guarantee competition and unbiased exchange between the respective services, the project team identified a need for normed interfaces [23].
Security: All data transmitted to and accessible via the MaP represents very sensitive information. Hence, the MaP needs to guarantee strict security aspects. That is, participants can create policies, e.g., who is allowed to view the flexibility offer, which is applied by the policy enforcement point (cf. chapter 2.4).

Accounting: Besides supporting services, there are also internal services, being intended for the MaP management. The most important one is the accounting service, which is used for automated payment of accomplished service actions. For this purpose, an automatic access to corresponding contracts is necessary.

Supporting Services

The described architecture enables participants to develop new innovative services. For this, the MaP provides mechanisms to register services and interfaces for integration. The objective is to develop the following initial services for the platform; further services will follow:

- Power Market: As already mentioned, current power markets such as balancing power exchanges [17] and ordinary power exchanges [19], have to provide a bidirectional connection. Upcoming regional power markets [20] can be connected to the MaP as well. Thus, companies can monetarize their demand response potential on different markets. Other services, like trading agents or forecast agents, can access information on current power prices.

- Trading Agents: Trading agents are equipped with a particular level of freedom, which allows them to take autonomous decisions in the context of energy purchases [24]. Algorithms, based on artificial intelligence can be applied in order to realize the agents.

- Forecast Agents: Forecasting is essential when it comes to optimal usage of flexibility. Information about future market trends are integrated into the profit maximization process, as it helps to decide when and at which market to place a certain amount of flexibility. Possible algorithms for solving the optimization problem include recurrent neural networks [25] as well as simpler heuristics which allow to approximate an appropriate solution more quickly [26].

Building on the mentioned fundamental components, the market platform is an initial approach; the long-term objective is to automatically utilize DR capabilities. The platform’s architecture is designed in a way that provides fast communication between companies and markets at low transaction costs. There is a first model for the German energy market being developed in order to show the platform’s feasibility. As the concept of the market platform is generic enough to also cope with different markets, an expansion to foreign markets is very likely.

2.3 Company-side platform

With the ongoing paradigm shift from the dissolving concept of the traditional automation pyramid to service-oriented manufacturing, referred to as a core-­enabler for Industry 4.0, the requirements for ICT-support of production processes are changing [27]. Since all things are offered as services this change is also indicated as Everything as a Service [28]. In favour of this service-­orientation, software functionalities will be divided into encapsulated services. Services are offered centrally by cloud platforms as well as in a distributed manner by edge computing and cyber-­physical systems (CPS). Because of the distributed functionality, the usage of open standards for the inter-­service communication is a central success factor [29]. However, existing approaches and products are quite the opposite: they are often tailored around the products and services offered by the vendor’s ecosystem and lack interoperability with other platform providers or integration of external systems such as the already described MaP [28].

The CoP comprises an infrastructure to systematically measure, model, communicate and modify energy characteristics of production processes. It exceeds the boundaries of traditional advanced metering infrastructures and automated DR approaches by a tight integration into production control (company side) and a trustful trading platform of energy flexibility products (market side). As a company-side enabler for automated and fast DR, it should not be designed in the form of a closed ecosystem, but on the contrary, it should follow a federative approach.

The CoP links humans, equipment, CPS and software services to gather, aggregate, analyze, and optimize production data on one hand and to allow for an energy-synchronized control of processes and equipment on the other hand and thus enabling an energy flexible operation of production.

The CoP’s operation mode depends on the company’s requirements and can either be a private, hybrid or public cloud. The architecture of the CoP is inspired by the service-oriented architecture proposed in [28] and depicted in Figure 3. Key components of the platform will be described hereafter.

- Company Portal: The Company Portal is the web-based access point for users to the CoP. It lists all services available for ordering, which can be chosen by an administrator of the respective company. Users can
search for and invoke services from this list which suite their tasks. Therefore, the Company Portal enables each user to achieve a task-dependent software support.

- **Manufacturing Service Bus (MSB):** The MSB is an integration layer for sensors, actors, equipment, CPS, IT systems, and software services. Therefore, it connects all components of the CoP itself as well as existing software and hardware within companies. Data routing and exchange between components can be defined using integration flows. These flows can either be created using an API or a graphical user interface (GUI). As discussed, open standards and interfaces are used to prevent vendor dependencies. Currently, the MSB supports industrial protocols (OPC UA, ROS, etc.) as well as IT protocols (REST, Websocket, MQTT, etc.). Due to its modular design further standards can be integrated easily [30].

- **Smart Connector:** The Smart Connector is an interface to integrate Programmable Logic Controllers (PLC) with a superordinate CoP in order to link software services with control and energy data from process level. Therefore, PLC protocols are vendor independently translated into IT protocols such as the ones mentioned with the MSB. In addition, the Smart Connector serves as a basis for edge computing. Services are not only deployed on the CoP but can also be deployed near-process on the Smart Connector. This approach takes into account that PLCs use a data resolution of milliseconds while internet-based communication in seconds is challenging nowadays.

- **Services:** Services and Apps are fundamental components of software-defined platforms. As part of integration flows they can interact with other services. In total, there are five types of services on the CoP [28] which could range from mostly manual services to machine learning enabled decision systems. First, there are integration services for equipment, which run typically on the equipment’s PLC or a Smart Connector in order to connect the equipment to the MSB. CPS Services combine sensors, actors and smart software to create highly flexible process components. Back-end Services refer to services providing defined, clearly delineated features without a GUI such as the CnI between CoP and MaP. Built on top of one or more Back-End Services with a GUI there are apps. They can either be implemented as web apps e.g. for dashboards or native apps e.g. for near-hardware sensor data acquisition.

- **Security:** Data processed by the CoP is very sensitive data such as load profiles. Accessed by an attacker, this data can allow unwanted insights to production utilization or process characteristics. Therefore, the CoP needs to guarantee certain security aspects. Among them are identity & access management and data anonymization as far as possible (cf. chapter 2.4).

While integrated via the MSB, all components in the CoPs ecosystem such as services, equipment or CPS can vendor-independently interact with each other. Therefore, the proposed approach allows for fully integrated production equipment using Smart Connector and MSB. Services are processing, managing and communicating data provided by the production shop floor. Among them are the CnI as a unified interface to the MaP, platform services such as identity management or service accounting, and services for production planning and control.

Besides these services the most important one regarding the monetarization of DR is a service for energy flexibility management. While provided by Smart Connectors, this service manages all available energy flexibility measures within the company and thus provides an overview of them. It can be decided, either by a human or an algorithm, which flexibilities are offered to the market and then be transmitted using the CnI to the MaP. Furthermore, when a DR option was called, this service is responsible for blocking the respective energy flexibility measures and to carry them out by the corresponding Smart Connector. Without the described approach of the CoP and its services all data and information handling to commercialize DR potential would have to be done manually.

### 2.4 Built-in security

The goal of the ESP is to connect the energy flexible companies with the energy markets. This brings up two ques-
tions: Which new threats brings this new technology to the companies, the markets, and the power grid? How can these threats be mitigated? For a company the first question is easy to answer. By using the CoP the company introduces a new attack vector which an attacker might use to place malware, steal sensitive information, or sabotage the company.

The threats for the markets differ in that an attacker can undermine the ability of the whole market (or special targets) to trade or manipulate the price of the market. These are general threats which every market faces, but when the ESP is used the CoP and the MaP can be a help in such attacks.

A simultaneous attack over the ESP infrastructure on markets and/or companies can even have a destabilizing effect on the power grid. Such attacks are more likely if all deployments have a homogeneous install base, since one exploit can be used to attack all deployments. It should also be noted that simultaneous attacks do not necessarily represent coordinated attacks. A scenario similar to the “DT” outage [31] can happen where a malware is triggering an unintended reaction in the ESP, even though the malware target is not part of the ESP. For this scenario, it is clear that the ESP needs to allow for heterogeneous installations.

The proposed ESP also introduces new types of data exchange between companies and the market. These communications need to be confidential and there integrity needs to be verifiable. But to gain value out of the information, it needs to be stored and processed. For sensitive information this might be undesirable. To handle such cases the ESP’s separation into CoP and MaP comes into play. A company has full control over its CoP instance and can apply the necessary security measures on it. Only if the company sees a value in exchanging information with the MaP, it might do so in a “need to know” fashion [32]. To enforce the “need to know” principle the CoP will use a mandatory access control system, which will be implemented by the MSB, CnI, and the CoP services. How a company can protect its assets if it cannot host a CoP, still needs to be explored.

As a central marketplace for flexibility trading the MaP is vital for ensuring the stability of overall ESP. This means that it needs extra hardening and a scalable architecture, since it is an obvious weak point. But the one (MaP) to many (CoP) mapping allows the MaP middleware to allow incoming communications from authenticated CoPs only. Inversely, CoPs only need to allow communications from the authorized MaP. A registration process has to be set-up for companies to register their CoP instances with MaP. If the registration cannot be bypassed and a company identity cannot be forged, then the MaP is able to filter unwanted communications. In addition the actions of a malicious company can then be tracked and more importantly it cannot repudiate its actions. The CoP has a similar benefit, since it only needs to trust the MaP and can verify the authenticity of the incoming communications.

We are still in the process of answering the question “How can these threats be mitigated?”, but the just presented information shows that the ESP’s new risks are considered adequately. For increased security, the system needs to evolve. Hence, the ESP is built in such a way that it can be adapted to new threats. In this context it is especially interesting how the companies and cloud providers will maintain their security in the long term. There needs to be done more research for the reduction of the security maintenance, so that the hurdle for self-hosting a CoP is reduced. The possible impact of ESP’s malfunctions on the power grid has yet to be investigated.

3 Conclusion and outlook

The ESP yields an overall approach for the trading with volatile energies and flexible productions in real time. It gives the industry partners the possibility to play an active part in the energy market and to utilize their DR potential. Nevertheless, secure communication and data exchange as well as data storage needs to be guaranteed in order to become a trustable platform. Additionally, the architecture’s scalability plays an important role for relocating the power generation towards renewable energies.

The platform’s corresponding research field is a quite new one. Thus, there is still much room for improvement. Technical problems include the smooth operation throughout the platform’s hierarchy. Standardized interfaces, as well as the integration of the stakeholders into the trading process are at least equally important. The aforementioned secure communication and data exchange is also base for further investigations. It is not only necessary for the platform’s immediate operability, but also to achieve a widespread acceptance.

Economic problems include the development of a management concept, in particular for the MaP, i.e., finding a person or company who is willing to host the platform. Though, the management of the CoP solely involves the appliance of private, hybrid or public clouds, there has much more work to be done on the MaP. This contains legal and regulatory questions, when deploying the platform.
over multiple countries, and monitoring of all services for accounting objectives.

In order to validate the developed concept, it is first tested in the ETA Factory, a model factory at the TU Darmstadt, before it is implemented by industrial partners. The ETA factory hosts a process representative for the metal processing industry. The process chain includes turning, grinding, hardening and different cleaning processes [33]. For validation purposes, various use cases have been identified within the factory to enable energy flexible operation. The derived knowledge will in turn be transferred into the platform's further development.

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