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Economic assessment of virtual power plants in the German energy market — A scenario-based and model-supported analysis☆,☆☆

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ABSTRACT

The energy transition ("Energiewende") in Germany will result in a substantial transformation of the energy supply system. Virtual power plants are expected to be important components of the new intelligent energy infrastructure. They aggregate beside different types of distributed generation units also active consumers and storage technologies in order to integrate these in a profit-maximising, system-stabilising, and sustainable way. The assessment of the economic performance of virtual power plants requires a scenario-based and model-supported analysis. In this relation, future energy market conditions are simulated using the scenario methodology. Starting from the year 2015, three scenarios have been identified that illustrate alternative energy developments in Germany by 2030. Based on these scenarios, the additional revenues potential of the modeled virtual power plant is identified when compared to an independent and non-market-oriented operation mode of distributed energy resources. According to the model results, revenues of the VPP can increase by 11% up to 30% in the analyzed scenarios in 2030 due to the market-oriented operation mode. Nevertheless, the amount and composition vary depending on technology-specific subsidies, temporary nature of power demand and price structures in the energy market. Fluctuating renewable energies are expected to benefit from the market-oriented operation mode in the virtual power plant, especially through the EEG direct marketing. The selective and regulated shutdown of renewable energies in times of negative electricity prices may lead to further cost savings. The utilization of temporary price fluctuations in the spot market and the demand-oriented provision of control power offer high additional revenue potential for flexible controllable technologies such as battery storage, biomethane as well as combined heat and power units. Finally, the determination of the long-term profitability of a virtual power plant still requires a full-scale cost–benefit analysis. For this holistic approach, the model results provide a reliable scientific basis.

1. Introduction

The energy concept of 2010/2011 of the German government includes ambitious targets for a sustainable energy system in Germany to be reached by 2050 (Bundesregierung, 2014). The realization of these targets shall be mainly achieved by an increased use of renewable energy (RE) and energy efficiency improvements (Viebahn et al., 2015, p. 656; Bertsch et al., 2014, p. 118). As a result of this development, the power plant fleet in Germany is changing successively. Fossil power plants are increasingly replaced by distributed energy resources (DER), such as RE or combined heat and power (CHP) units. The RE, however, have hitherto attained market maturity only in individual cases. A targeted funding is currently still necessary.[1] Therefore, new approaches are required to integrate DER in the energy-economic competition over the long-term. In this context, virtual power plants (VPP) are qualified to implement these requirements effectively. Distributed generation units, active consumers, and energy storage can be connected via information and communication technology (ICT) and aggregated into an intelligent plant network. This enables new trading options in the energy market as well as opportunities for the optimization of frequency and voltage stability of the power supply system. In addition, greenhouse gas emissions can be reduced significantly through the market-oriented integration of renewable energies and efficient technologies by VPP.

Against this background, the present article analyzes the economic performance of VPP in the German energy market. Based on specific

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This article contains an economic potential analysis of virtual power plants in the future energy market. Based on assumptions about the future development of the energy market, the potential additional revenues of a virtual power plant are determined by two mixed integer programming models.

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[1] The support of RE and CHP-units primarily takes place through the German "Erneuerbare-Energien-Gesetz — (EEG)" (Renewable Energies Act) and "Kraft-Wärme-Kopplungsgesetz – (KWKG)" (Combined Heat and Power Act). Regulatory requirements simultaneously support the aspired market integration.

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energy scenarios and two mixed integer programming models, it is examined if controlled DER can generate higher trading revenues until 2030 than independently operated DER. For this purpose, the fundamental energy-economic conditions and trading options of the VPP are explained in Section 2. In Section 3, a scenario analysis is then carried out. Several consistent scenarios are developed through varying essential key factors of the energy economy in a reasonable range. Afterwards, Section 4 carries out an economic potential analysis. The additional revenue potential is determined for a modeled VPP when compared to an independent and not market-oriented operating mode of DER. In Section 5, the respective model results are presented and analyzed. Section 6 summarizes the present article and provides a recommendation for the sustainable planning and development of VPP.

2. Basic aspects of the German energy market

The development of competitive structures in the German energy market in the context of the European liberalization leads to a realignment of traditional value-generating segments. The generation portfolio, power supply infrastructure, and market design of the energy sector are changing in alignment with the German “Energiewende”. This transformation is a gradual process, which allows that new companies enter the market, novel business models arise, and innovative technologies, such as VPP-systems, are developed.

2.1. Energy system transformation

The current transformation process of the German energy system mainly takes place in the power generation, grid infrastructure, and consumer segment. In the field of power generation, RE and CHP-units with comparatively small capacities increasingly replace large-scale power plants. The long-term rising price level of fossil fuels and CO_2 allowances (IEA, 2014, p. 45 and 48) are expected to lead to a price increase of the marginal costs of fossil power plants. In addition, the price-reducing effect of RE on electricity prices (merit order effect) impairs their economical operation (Fürsch et al., 2012, p. 1). The gross electricity generated by RE in Germany 2014 amounted already to 161 TWh/a[2] (BMWi, 2015). As a result of the ongoing support for RE, an increase of the RE capacity to 310 TWh/a is expected by 2030 (Nitsch, 2014, p. 20).

The growing share of DER in the German generation portfolio leads simultaneously to the emergence of new requirements for the power supply infrastructure. Unlike fossil power plants, the construction of RE and CHP-units is carried out at meteorologically favorable areas or in the vicinity of consumption (heat sink). Therefore, DER also feed into different voltage levels of the power supply system. Bidirectional electrical power flows and fluctuating feed-ins by weather dependent RE, such as photovoltaics (PV) or wind turbines, are the result. The traditional power supply infrastructure cannot completely absorb these new energy flows and fluctuations, because their technical components and central control concepts originate predominantly from the 1960s to the 1970s (Lehnhoff, 2010, p. 18). To solve these challenges, two basic measures are currently being pursued. On the one hand an expansion of the transmission and distribution capacities is realized to take up and transport the growing share of fluctuating feed-ins in the long-term. On the other hand, the technical components of the power supply infrastructure are increasingly equipped with intelligent ICT. The objective of this measure is to gradually develop a smart grid, which automats and integrates feed-ins as well as consumption behavior of all actors in the energy market in real time (BDEW, 2014; IEA, 2011, p. 6).

Apart from the electricity generation and power supply infrastructure, the role and behavior of the consumer also changes. While the quantification of the electricity consumption has traditionally been accomplished by standardized load profiles or by registered load profile measurement (§ 12 StromNZV, 2005), intelligent measurement methods, like smart metering, are increasingly used today to measure the consumption behavior in real time. The reinforced use of smart meters combined with flexible tariffs is also highly relevant for energy suppliers and service providers in order to tap the load shifting potential of the consumer. Furthermore, consumers also increasingly operate own generation units with comparatively low capacity.[3] The produced electricity is either consumed directly or fed into the local distribution grid. The particular challenge is to offer active consumers economic incentives to market their produced electricity and to shift the load in periods with lucrative market conditions.

2.2. Functionality of virtual power plants

With the transformation of the generation portfolio, grid infrastructure, and consumption pattern, the control effort as well as the coordination requirements of the energy system increases simultaneously (Appelrath et al., 2012, p. 22; Sučić et al., 2011). In this context, VPP gain in importance,[4] because they aggregate single distributed generation units (RE and CHP-units), active consumers, and storage technologies with help of ICT to an intelligent energy network (Doleski, 2014, p. 692; Miceli, 2013, p. 2289; Nikonowicz and Milewski, 2012, p. 135). Through the DER bundling, among others, prequalification requirements of several trading options (e.g. control power market) are easier to fulfill. In addition, new value creation potentials, such as market-oriented generation or load shifts, also open up. Besides these economic benefits, VPP also make a significant contribution to climate protection. Due to the substitution of inefficient fossil power plants by bundled DER, greenhouse gas emissions can be avoided in the long-term (Appelrath et al., 2010, p. 12). Depending on the VPP composition of the DER portfolio, emissions of a replaced fossil power plant are almost completely avoided or significantly reduced. For these reasons, VPP are an important technology to realize the ambitious energy and climate protection goals of the German government.

The VPP main functionality includes the schedule and trading optimization of the bundled DER portfolio (Faria et al., 2015, p. 6235). For this purpose, all integrated generation units, active consumers as well as battery storage must firstly be equipped with sufficient ICT to guarantee a continuous information exchange between the control system and the central database of the VPP. Based on imported master and transaction data, the scheduling and trading optimization of the bundled DER portfolio consists of three process steps (Fig. 1).

In the first step, all required forecast data concerning weather, market prices, generation, and load are imported via defined interfaces into the VPP-system. Historical data are also included as empirical values and consolidate the forecast base. Afterwards, the operational planning of the DER portfolio takes place within the schedule and trading optimization to determine the optimal bidding strategy (Riveros et al., 2015). This occurs automatically or manually in specified time intervals with the involvement of economic, technical, contractual as well as forecast master and transaction data. After a plausibility check, the generated schedules are dispatched in form of control commands to each single DER of the VPP. Finally, it is necessary to monitor the compliance of the schedule specifications and therefore also the implementation of the optimized trading strategy. By measured data of DER and grid conditions, a persistent target/actual comparison is performed in real time in order to identify early schedule deviations and to initiate measures to correct the respective control commands.[5]

[2] This currently amounts to 26% of the total gross electricity generation in Germany.

[3] Customers who consume and produce energy are classified as active consumers or “prosumers”.

[4] With the development of the VPP, the strategic objective is often pursed to substitute fossil power plants in the long term (Appelrath et al., 2010, p. 12).

[5] Schedule deviations, for example, can be the result of forecast errors and technical malfunctions of DER or ICT.