Comparing flexibility options on the supply and demand side of the German electricity market

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Abstract

In order to exploit flexibilities on energy markets in the most profitable way, providers or aggregators need suitable techno-economic models. In this paper, we illustrate the potential role of operation research on this field by investigating whether optimization models can help to understand, predict and improve the participation of actors offering flexibility options in the electricity markets. First investigations show that multiple ways to make use of flexibility potentials existist, which differ signficicantly in terms of revenue or saving potential and required effort. The implementation and operation of virtual power plants (VPPs) could therefore benefit from planning tools that help to speedily assess the most efficient choices from a portofolio of flexibility options.

1 Introduction

The increasing share of volatile electricity production in wind turbines and photovoltaic modules requires increasing flexibility both on the supply and demand side of the German electricity sector (Pecas Lopez et al., 2007). In principle, there are four different flexibility options on both the supply side (1-3) and the demand side (4) (BMWi, 2014; Connect, 2014; Siano, 2014):

1. Flexible conventional and renewable production;
2. Efficient and effective energy grids;
3. storage systems (e.g., pumped-storage);
4. Flexible demand from industry (e.g. shiftable industrial processes), commerce, households and electric vehicles (EVs).

On both sides, however, the unearthing of decentralized potentials is stalling most notably because of the substantial investment required for constructing infrastructure (e.g. smart meters, on the demand side or additional energy storages on the supply side), user acceptance problems, lack of incentives, and extensive regulatory requirements on energy markets (Geelen et al., 2013; Kim, 2011).

In particular, many business cases for demand side integration (DSI) – defined as the consumer's ability to alter his or her energy consumption pattern in response to time-dependent electricity prices or incentive payments (Strbac, 2008) – are hindered by extensive requirements concerning minimum order sizes on energy markets, security levels, contract or reaction time or market time frame (BMWi, 2014). Due to this reason, most energy end-users are aggregated by intermediaries or utilities to participate in DSI (Chiu et al., 2009). On the supply side, the latest renewal of the Renewable Energy Law (EEG, 2014) seeks to increase the number of biogas plants that react flexibly on changes in market prices. So far, however, the number of biogas plant operators that have taken advantage of the subsidies for such adaptations to their plants is relatively low (6.9% of the maximum eligible plant capacity of 1.35 GW have been realized until November 2015).

To overcome the regulatory hindrances, bundling and combined control of decentralized units in portfolios may help to overcome the above-mentioned difficulties and thus unearth the potential of flexibility options. Such portfolios are offered by service providers – known as curtailment service providers (CSPs), demand response providers (DRPs) or aggregators – whose business model is to manage and combine various demand-side and supply-side resources in the most profitable way. To illustrate the potential role of operations research in this field, we thus investigate whether optimization models can help to understand, predict and improve the participation of actors offering flexibility options in the electricity markets in this paper.

2 Flexibility options

Numerous flexibility options are available to guarantee the secure, cost-effective and environmentally friendly synchronization of electricity production and electricity consumption. Therefore, precedence can be given to selecting the most inexpensive option. In the following, two promising fields of applications on the energy supply and energy demand side are presented; commercial heavy duty electric transport vehicles operating in closed transport systems (ETVs) and biogas plants. Regarding the energy demand side, EVs seem to be good candidates for initial DSI applications, such as the vehicle-to-grid concept (Kempton and Tomić, 2005) or smart charging (Goebel, 2013), mainly because they remain idle for the greater part of the day and it is thus possible to utilize the corresponding load-shifting potential for DSI (see also: Gu et al., 2013). Due to the high requirements on most DSI energy markets (see Section 1), , commercial ETVs seem to be particularly suitable for a broad implementation of DSI; it is possible to pool the ETVs – each with a considerable battery storage capacity – on company grounds and act as a single entity on energy markets (Schmidt et al, 2014). The energetic potential of using ETVs as flexibility option is difficult to assess as, so far, only few ETV fleets are in use (e.g., in the port of Hamburg).Regarding the energy supply side, biogas plants are both a renewable energy source, abundantly available in Germany and capable of adapting electricity production flexibly. The flexibility potential of biogas plants in Germany is estimated to be very high, up to 20 GW positive and negative power (Krzikalla et al., 2013).

2.1 Flexible demand

In order to assess the potential of DSI for this application context, a research project (called BESIC) with a container terminal operator was initiated in 2012. Within the frame of the project, 10 of the terminal's 80 conventional diesel-powered automated guided vehicles (AGVs) have been substituted by battery-powered AGVs (B-AGVs). The main goal of the project is to assess how the charging flexibility of the B-AGV fleet can be optimally utilized for DSI (see also: Schmidt et al., 2015a). To apply DSI programs in practice, a simulation model was established which enables the fleet operator to forecast the state of charge of the batteries for approx. 40 hours. This is necessary because it must be ensured that the logistic processes of the terminal operator are not negatively affected by influencing the charging processes. So far, it was found that controlled charging based on variable prices for electricity seems to be the most promising option for the fleet operator, mostly because of significant cost-saving potentials identified and relatively simple feasibility (Schmidt et al., 2015b).

2.2 Flexible renewable production

In order to find a more market-based way that utilizes biogas plants' ability to react to fluctuating electricity production from other renewable energy sources, the most recent versions of the EEG in 2012 and 2014 encourage biogas plant operators to produce electricity when the spot market prices is highest. In Germany, the largest spot market volume is traded on the EPEX.

The two most visible instruments to achieve these aims are commonly referred to as market premium and flexibility premium. While the market premium is paid on top of EPEX revenues to encourage direct marketing of produced renewable electricity at the energy stock exchange, the flexibility premium is designed to give an incentive to biogas plant operators to compensate the fluctuating production from wind turbines and photovoltaic cells instead of contributing to basic load.

3 Materials and Methods

In the context of VPPs and DSI, two different kinds of optimization models can be applied. On the demand side, the cost of electricity purchases at the EEX can be minimized. On the supply side, notably for biogas plants, a maximization approach can be used to decide when to produce and sell electricity for the market. In this section, we illustrate both optimization approaches. While several models for either electricity demand or supply have been presented (e.g. Panžić 2013, Oskouei 2015), only few papers present combined approaches (e.g. Nosratabadi 2016). It must be noted that the applied optimization approaches are simplified as, for example, we do not consider grid costs, partial load, or the the potential problems of simultaneous ETV charging.

3.1 Cost minimization on the electricity demand side

Under current energy market conditions, the DSI programs *controlled charging based on variable electricity prices* can be realized by procuring the required power on the electricity spot market and shift the energy demand to the hours with the lowest prices. A precondition for the implementation of this DSI program is the availability of information regarding the energy demand and charging flexibility of the B-AGV for a certain period. The main goal of this DSI program is to optimize charging costs C_{TF} by shifting the charging times to fully charge a battery system to the M time slots in which the electricity spot market prices per time slot (i) are the lowest. For that, let I be the number of 15-minute time slots i in which a vehicle is connected to the grid, and thus a subset of the set T of 15-minute intervals t in the year as a whole. In the interest of constraining the charging processes to the hours with lowest prices for electricity procurement, we use the following function as a decision variable

$$x(i) = \begin{cases} 1 \; for\ charging\ a\ battery\ in\ time\ slot\ \ i \\ 0 \; for\ not\ charging\ a\ battery\ in\ time\ slot\ i. \end{cases} \qquad (1)$$

Next, we calculate the hourly electricity demand $\mathrm{d_t}$ per time slot t of 15 minutes in which the battery is charged under consideration of the charging efficiency η and the charging power $W_{Charging}$ (in kW). Thus, we derive

$$d_t(x(i)) = \frac{W_{Charging}\ \frac{1}{4}h}{\eta}\ x(i). \tag{2}$$

The corresponding optimization problem for one time frame resolves to

$$\min_{x(i)} C_{TF} \sum_{i=1}^{I} p_{spot}(i) d_t x(i), \tag{3}$$

subject to

$$\sum_{i=1}^{I} x(i) = M\ \forall\ x(i) \in \{0,1\}; i \in \{1, \dots, I\}, \tag{4}$$

in which the first constraint states that each battery system must be fully charged at the end of each charging period as requested by the terminal operator.

Using driving profiles based on the simulation model developed, a cost-saving potential of up to 30% compared to the case of no DSI program application was calculated for the period of one year (annual charging costs uncontrolled charging: €129,164 / annual charging costs controlled charging €194,343).

3.2 Revenue maximization on the biogas-based electricity supply side

For the supply side, the optimization problem is framed by the regulations in the EEG of 2014. Whether biogas plants produce or use the time window in which operators can wait for higher electricity prices is therefore determined by a) the ratio of power generation capacity P_{inst} to biogas production capacity P_{biogas} and b) the remaining available biogas storage capacity at time m cap_m. Furthermore, we can assume that biogas plants will be operated to the full potential of their biogas production capacity over the year. Given that the plant produces at its full installed electrical capacity P_{inst} whenever it produces (which is not necessarily the case in reality), the biogas plant operator's revenue maximization problem can therefore be simplified to

$$max\left(\sum_{i}^{I}(p_i x_i P_{inst})\right), \tag{6}$$

s.t.

$$\frac{\sum_i^I x_i}{|I|} = \frac{P_{biogas}}{P_{inst}}, \tag{7}$$

$$|I|P_{biogas} - P_{inst}\sum_{i=0}^{I} x_i \leq cap_{max} - cap_{i=0} \tag{8}$$

4 Discussion and Conclusion

Existing enterprises like "Next Kraftwerke" offer services similar to those described in Section 2. Combined flexible supply and DSI has therefore proven to be possible already. The actual realization of such measures on a greater scale seems to be hindered by different factors on the supply versus the demand side. On the supply side, lack of monetary incentives is frequently cited as a reason for stagnation in the flexible power supply by biogas plants. On the demand side, regulatory hurdles make it difficult to motivate industrial electricity consumers to participate in demand side integration schemes. This is partly due to the fact that electricity consumers are usually primarily engaged in industries other than energy, and therefore face numerous constraints in their ability to reduce (or expand) their demand.

As shown in Section 3, the knowledge of day-ahead prices makes it possible to adapt flexible electricity consumption and electricity supply to market signals. As aggregators continuously control increasingly large numbers of supply and demand actors, constrained optimization may become a helpful means in the automatization of the operation of flexibility options. Furthermore, as actors in the electricity market already attempt to optimize their reaction to price signals, properly designed models can help to understand market participants' behavior. Identifying reasons for more or less enthusiastic behavior may help policy makers to improve regulations, and subsequently, market designs.

The overarching goal of developing a system of specific optimization models would therefore be to rank flexibility options and choose the best ones first in order to maximize the efficiency of responding to price signals. Aggregators, or any "virtual power plant" consisting of various supply-side and demand-side flexibility options, are thus enabled to determine an optimal reaction to price signals. It could therefore be attempted in the future to develop a comprehensive decision support system based on constrained optimization models that helps to choose the best flexibility option to react to market signals.

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