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Integration scenarios of Demand Response into electricity markets: Load shifting, financial savings and policy implications

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HIGHLIGHTS

- Comparison of 3 scenarios to integrate Demand Response into electricity markets.
- These are: optimize procurement, offer as control reserve, avoid balancing energy.
- Ex post simulation to quantify financial impact and policy implications.
- Highest savings from load shifting with a cost reduction of 3%.
- Model suggests reducing bid sizes, delivery periods and time lags as policy issues.

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ABSTRACT

Demand Response allows for the management of demand side resources in real-time; i.e. shifting electricity demand according to fluctuating supply. When integrated into electricity markets, Demand Response can be used for load shifting and as a replacement for both control reserve and balancing energy. These three usage scenarios are compared based on historic German data from 2011 to determine that load shifting provides the highest benefit: its annual financial savings accumulate to €3.110 M for both households and the service sector. This equals to relative savings of 2.83% compared to a scenario without load shifting. To improve Demand Response integration, the proposed model suggests policy implications: reducing bid sizes, delivery periods and the time-lag between market transactions and delivery dates in electricity markets.

1. Introduction

In large parts of the world, renewable energies are the chosen resources to replace fossil fuels in the context of energy production. However, the associated integration of renewables has triggered fundamental changes in the organization of the energy sector. One of the these changes is the establishment of Demand Response facilities, which shift load away from the peaks to smoothen overall energy consumption.

Demand Response (DR) allows for the management of the demand side of electricity markets by shifting power demand according to the fluctuating supply side. It is defined by the U.S. Department of Energy (2006) and the Federal Energy Regulatory Commission (2006) as "*changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.*" Active management of the demand side can help to compensate for an increase in the electricity price (Aghaei and Alizadeh, 2013; Bergaentzlé et al., 2014; Dyson et al., 2014; Klobasa, 2010) and volatility (Bierbrauer et al., 2007; Valenzuela et al., 2012). Consequently, integrating Demand Response into electricity markets can occur in several ways (e.g. Aghaei and Alizadeh, 2013; Madrigal and Porter, 2012).

Policy makers need to formulate a corresponding *policy design* that enables and appropriately encourages the use of Demand Response. As a result of recent efforts towards liberalization, such policies are most likely implemented in the form of an *efficient market design*. However, such markets and the roles of their participants need to be carefully designed to solve the complex underlying allocation problem (Cramton and Ockenfels, 2012; McAfee, 1998). For instance, Germany did not introduce limits to the infeeds from renewable energies at first (in comparison with other countries, such as Switzerland); only the 2014 revision of the *Renewable Energy Sources Act* (EEG) established first forms.

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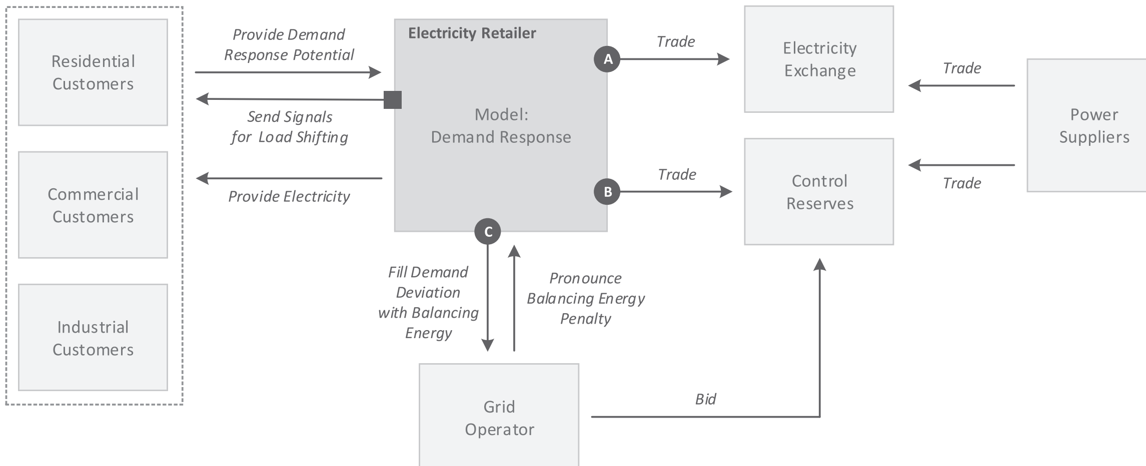

Fig. 1. Overview of relevant stakeholders interacting with electricity retailers in the German electricity market, as well as the optimization model to manage Demand Response activities.

Therefore, the following characteristics of market designs need to be carefully chosen and the corresponding *policy implications* derived (Koliou et al., 2014):

1. **Contract duration**. One important aspect of markets is the contract duration (Bandiera, 2007; Just, 2010). While there are multiple theoretical propositions on contract duration, a small number of these have been tested econometrically (Saussier, 1999). For instance, costs of a long-term contract increase with transaction-uncertainty level (Saussier, 1999). Even though this statement was tested for the coal market, similar effects are likely to be present when looking at the delivery of electricity or contracts for load shifting.
2. **Contract volume**. Electricity markets usually require a minimum bid size. For instance, DR potential is often traded in blocks of 1 MW or 5 MW.
3. **Reliability**. Most sources of Demand Response originate from highly flexible sources. For instance, aggregations combine the demand flexibility of renewable energy sources or several households and sell this as load shifting capacities. However, a 100% reliability may not be guaranteed and, instead, policy makers need to find alternative (or weaker) formulations for the reliability of offered DR (Paulus and Borggrefe, 2011).
4. **Time lag between trading and delivery**. Depending on the auction design, the minimal time span between trading and delivery varies significantly (Borggrefe and Neuhoff, 2011). For example, trades are often completed on an intra-day or day-ahead basis, while even longer scheduling horizons of up to several weeks in advance are not uncommon. This immediately poses a trade-off between long-term system stability as opposed to the possibility of optimally adjusting to the feed-ins from renewable energy sources (e.g., Koliou et al., 2014).

In order to provide insights into the above questions, this paper analyzes different scenarios in which DR is integrated into the German electricity market. We go beyond state-of-the-art and utilize real market data to quantify and compare the financials around the scenarios in order to derive dedicated policy implications. Depending on the actual market design, policy makers can considerably influence the efficiency and the way in which Demand Response is used. While some scenarios seem not profitable in the status quo, we perform a what-if analysis to see what makes them financially more rewarding.

The remainder of this paper is structured as follows. In Section 2, we discuss strategies to integrate Demand Response activities into existing electricity markets. Subsequently, we review related work on the financial dimension of Demand Response (Section 3). For each scenario, Section 4 models optimal decisions to gauge financial savings. In Section 5, we present the results by comparing Demand Response activities across different application scenarios. Finally, Section 6 summarizes the findings and discusses policy implications to improve the integration of Demand Response into electricity markets.

2. Integrating Demand Response into electricity markets

This section presents stakeholders in the electricity market (more precisely, we use the German market for the subsequent specifications and evaluations). This is followed by a description of the electricity market structure. Both then motivate different scenarios for the integration of Demand Response.

2.1. Stakeholders

One of the major challenges is to operate electricity markets successfully by guaranteeing grid stability. Due to highly volatile supply and demand, electricity grids may become unstable when large deviations from the desired power frequency occur. The maintenance of grid stability requires power frequency to be controlled continuously. Hence, grid operators (see Fig. 1) have to immediately counteract any imbalances by means of short-term *control reserve*. While grid operators execute balancing activities in response to individual deviations in power frequency, the emerging costs are distributed across the associated electricity retailers. Whenever electricity retailers face unexpected deviations in demand or supply that might affect grid stability within their control area, they request the so-called *balancing energy*, which comes at varying penalty costs.

2.2. Electricity market structure

Most electricity markets in developed countries (e.g. Kirby, 2004) can be divided into three categories, namely, a product market, a control reserve exchange and balancing energy (cp. Fig. 2). As all three categories are suitable for Demand Response, this section elaborates on the possible strategies (based on the above scenarios) for Demand Response integration.