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Demand response in liberalized electricity markets: Analysis of aggregated load participation in the German balancing mechanism

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ABSTRACT

Power systems are in the midst of radical changes as a result of steadily rising demand, advanced technology integration and increasing penetration levels of renewable energy sources. Such developments have brought about increasing recognition of consumer behavior and the provision of DR (demand response). The aggregation of small loads as a DR flexibility resource allows end-users to participate in electricity markets and aid in maintaining dynamic system stability. An analysis of the German balancing mechanism illustrates that DR is undermined by three mechanism design aspects: minimum bidding volume, minimum bid duration and binding up and down bids.

1. Introduction

The European Union is aiming to reach a 20% increase in energy efficiency and 20% emission reduction compared to 1990 levels, in addition to 20% of electricity production from RES (renewable energy sources) by 2020. As per Directive 2009/28/EC RES generators are receiving priority access to the electricity grid [1]. Together with electrification of transport and heating, these developments are imposing big technical and financial challenges for maintaining system reliability [2,3]. For decades, the provision of electricity has been characterized by centrally controlled systems with overcapacity ensuring security of supply. Following the liberalization of electricity markets, discussions have shifted the focus of security on measures from the supply side. Besides increasing generation capacity, demand may also be exploited [4].

Modification of electricity consumption in response to price of electricity generation and state of system reliability is regarded as DR (demand response) [5–7]. The implementation of DR is one of the most investigated solutions oriented towards the improvement of electricity market efficiency and maintenance of power system reliability. Within several European countries, there are established programs which currently harness the largest and most energy intensive industrial customers through dynamic tariff schemes or direct use of load as part of their system balancing activities [3]. The industry is already rooted as a flexibility resource, while residential consumers remain untapped. Industrial users in Europe consume 36.1% of the total electricity demand, while households and services account for 30.9% and 30.4%, respectively [8].

In the European SG (Smart Grid) initiative,[1] there is increasing interest in the wider implementation of DR opportunities across smaller commercial and residential groups. This is due to technological developments in low-cost power electronics and ICT (Information Communication Technology) along with general growing recognition of the importance of customer behavior [3]. The utilization of smaller loads requires detailed knowledge of customer potential through the definition of demand segments, knowledge of DR and customer aggregation clusters [9]. By aggregating smaller consumer's loads (like households or small businesses), DR capacity can also be provided for dynamic flexibility in the short term [10–12].

A critical new stakeholder in the electricity market is the aggregator. The aggregator is an actor, who "… offers services to aggregate energy production from different sources (generators) and acts towards the grid as one entity, including local aggregation

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[1] The SG initiative aims to intelligently integrate all connected users (including end users) in order to efficiently deliver sustainable, economic and secure electricity supplies [14,15].

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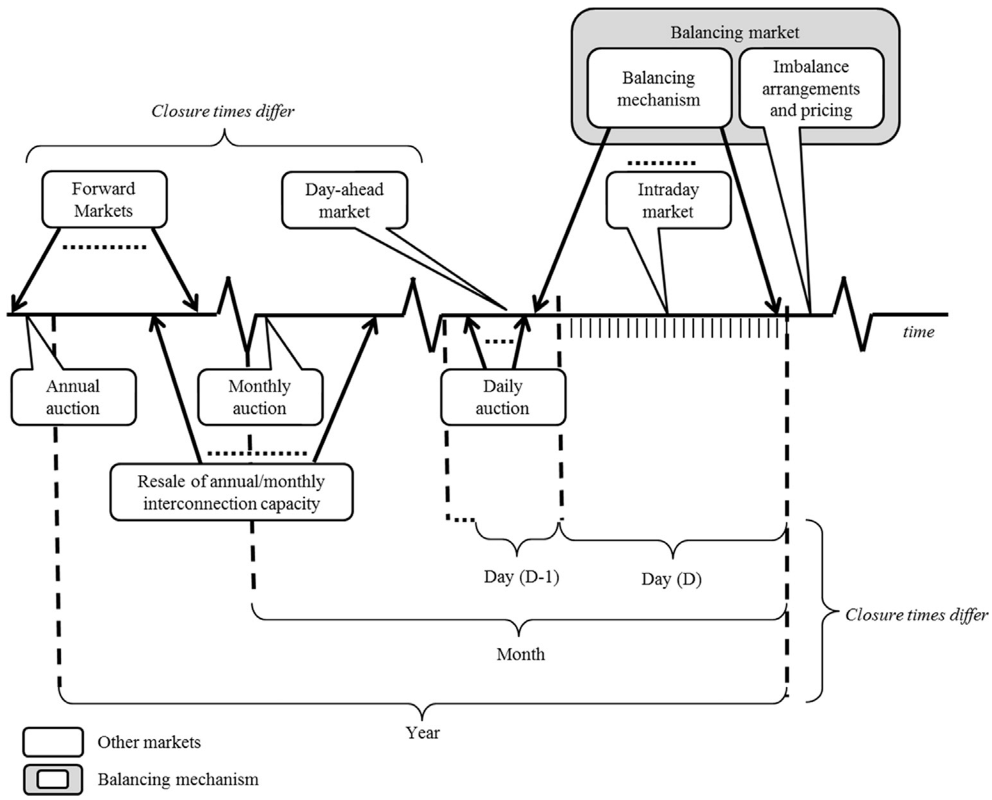

Fig. 1. Time sequence of electricity markets [23].

of demand (Demand Response management) and supply (generation management)" [13,11]. The aggregator enables demand response from smaller consumers due to load bundling capabilities, which can be offered in the wholesale electricity market [11]. In future power systems, aggregators control multi-fuel, multi-location and multi-owned VPPs (virtual power plants), which aggregate capacity from DERs (distributed energy resources)[2] equivalent to the capacity of a power plant in order to facilitate integration both in the physical system and in the market [16]. For the remainder of this work, when the authors refer to demand response it is in terms of aggregated load from end-users forming a VPP.

Previous research reveals that the most dominant share of such "intermittency cost" is balancing costs due to imperfect wind and solar forecast, followed by transmission and distribution network costs [2,17]. Due to measures in restructured markets focusing on the short-run modifications of behavior [18], the authors concentrate on the participation of aggregated demand response from small end users in the real-time balancing energy market, which is considered the last market in which electricity can be traded [19]. Exploitation of demand side flexibility is expected to yield positive benefits in the economic efficiency of deregulated electricity markets, enhance reliability and relieve congestion and network constraints [18,17].

So far, there has been a lot of discussion on the importance of utilizing DR in European electricity markets (with large RES penetration). Nonetheless, there has been minimal analysis of existing electricity market organization and how DR participation is impeded with current requirements. The authors aim to use this work to fill the knowledge gap, starting with a closer look at the European electricity markets and the motivations and initiatives for engaging aggregated demand response as a reliability resource. Section 2 summarizes the organization of the European balancing mechanism. Section 3 utilizes the German market as a case study in order to illustrate the complexity involved in balancing participation. The analysis continues with a discussion in Section 4 of the current barriers to aggregated DR. The paper concludes with a summary of the findings and some recommendations to policymakers.

2. Motivation and initiatives for engaging demand response

Power systems have some inherent undisputable characteristics. Firstly, in real time, supply and demand must always be in balance. Secondly, electric power is not economically storable at a large scale. Moreover, costs of producing electrical energy vary considerably with respect to technology and fuel input. Finally, consumption of electric energy varies over time on account of consumer behavior. As a result of these properties, the provision of electricity requires balance management necessary to safeguard the security of electricity supply from producers to consumers through the electricity network [19,21]. The European power system has a set point of system frequency balance which must be narrowly maintained at 50 Hz. Electricity is thusly traded in organized markets in accordance with the prescribed system limitations. In this way, electricity markets can be classified with the time of delivery in forward, day-ahead, intra-day and balancing markets (see Fig. 1 for details). Note: about half of the electricity consumed is traded in forward markets, which take place days and even months ahead of delivery usually consisting of long-term bilateral contracts. The day-ahead spot market plays an important role in

[2] DERs consist of two aspects: (i) generation located within the distribution system or on the customer side of the meter and (ii) demand-side resources consisting of both local generation and incentives to reduce demand including energy efficiency and demand management [20].