



Multi market bidding strategies for demand side flexibility aggregators in electricity markets

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ABSTRACT

Due to the electricity systems' increasing need for flexibility, demand side flexibility aggregation becomes more important. An issue is how to make such activities profitable, which may be obtained by selling flexibility in multiple markets. A challenge is to allocate volumes to the different markets in an optimal way, which motivates the need for advanced decision support models. In this paper, we propose a methodology for optimal bidding for a flexibility aggregator participating in three sequential markets. We demonstrate the approach in a generalized market design that includes an options market for flexibility reservation, a spot market for day-ahead or shorter and a flexibility market for near real-time dispatch. Since the bidding decisions are made sequentially and the price information is gradually revealed, we formulate the decision models as multi-stage stochastic programs and generate scenarios for the possible realizations of prices. We illustrate the application of the models in a realistic case study in cooperation with four industrial companies and one aggregator. We quantify and discuss the value of flexibility and find that our proposed models are able to capture most of the potential value, except for some extreme cases. The value of aggregation is quantified to 3%.

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1. Introduction

Due to the growing share of intermittent generators connected at various voltage levels, electrification of the transport sector and the development of new consumption patterns, the electricity systems face an increased need for flexibility [[1–3]]. Eurelectric defines flexibility as “*the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system*”. Since most of the above-mentioned changes come at the distribution grid level, the flexibility is in particular needed at the demand side.

In order to exploit the flexibility potential of smaller customers, the concept of aggregation is important [1]. A flexibility aggregator is an entity that pools small volumes of flexibility and acts as an intermediary between providers and procurers of this flexibility. Moreover, the flexibility aggregator makes market access possible for demand side flexibility, by reducing transaction costs and pooling small volumes to large enough for market participation.

However, an issue to be addressed is how to make a profitable business case for a flexibility aggregator. One possible approach is to sell the aggregated demand side flexibility in multiple markets, and hence create multiple revenue streams.

Also ENTSO-E¹ supports the idea above by stating that the demand side should participate in all markets [4]. To accomplish this, they suggest that market rules should be amended to enable the work of aggregators.

In response to the increased need for flexibility, a large number of concept studies and demonstration activities related to market design changes have been initiated. Some focus on the change of rules in existing, while others introduce new markets.

The ECO-Grid project proposes a new, local real-time market to balance the power system. The market is bid-less and the market operator sets a price every 5 min for flexible resources to respond to [5]. The new market fits into the existing market regime between the regulating power market and the frequency-controlled reserves, and opens for smaller units to participate. A neighborhood market is proposed in the Nobel-project [6] aiming at trading

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¹ European network of transmission system operators for electricity, www.entsoe.eu.

locally produced renewable generation. The market model is based on a stock exchange model with continuous trading for 15 min' time slots. The iPower project introduces a clearinghouse for flexibility services to facilitate ancillary services at the DSO level ([7] [8]) to avoid local congestion. They distinguish between service types for reservation and scheduling. Activation signals are sent out, and the flexible resources must respond within 15 min. The idea of splitting into reservation and scheduling is also supported by Rosen & Madlener [9], who propose a weekly auction for reservation of capacity for every hour of the days in the following week. A local market framework to exploit flexibility from end users is also proposed by Torbaghan et al. [10]. They split between ahead planning including day-ahead and intra-day mechanisms, and real-time dispatching. The DSO is the local market operator, and the energy programs are set such that there will be no congestion issues in the distribution grid. If the market-based planning fails, the DSO will perform real-time dispatching to resolve congestion issues.

The Horizon 2020-project EMPOWER² elaborates a local market concept with three basic types of markets: One for local electricity, one for local flexibility and one for other services [11]. The local flexibility market provides flexibility services for local congestion and voltage control. The Smart Energy Service Provider, SESP, acts as a flexibility aggregator with long term contracts with the flexible consumers and prosumers on one side, and the DSO on the other. The market has the time granularity of 15 min [12].

A review of markets for demand side flexibility is given by Eid et al. [13]. They divide the different markets into ancillary services, system balancing and network congestion management, spot markets and generation capacity markets.

Another review is given by Hu et al. [14], who focus on barriers to integrate variable renewable electricity into the wholesale electricity market. They claim that an overhaul is needed for the current EU electricity market design and suggest higher time resolution of trading products, later gate closure times and capacity-based schemes.

Although some of the references above focus on the local and other on the wholesale side of the market, there are some common features: Reservation of flexibility capacity for later use, activation of flexibility near real-time and an energy market for the day-ahead or shorter. Based on these ideas, in this article we define a generalized market design which we believe is representative for a future market design both at the wholesale and the local levels. The design includes the following markets:

- An options market (OM), where flexibility capacity is reserved for potential later use. The trading horizon is several days.
- A spot market (SM), where electricity is traded for the day-ahead or shorter with a time granularity of 1 h or less.
- A flexibility market (FM), where flexibility is activated in real-time or close to real-time.

Note that this market framework is partly similar to already existing electricity markets at the wholesale level. One example is the Norwegian market regime, where Statnett's³ Tertiary reserves options market ("RKOM uke"), Nord Pool's⁴ Elspot day-ahead market and Statnett's Tertiary reserves market ("RK"), correspond to the OM, SM and FM, respectively.

² Local Electricity Retail Markets For Prosumer Smart Grid Power Services, www.empowerh2020.eu.

³ Statnett is the Norwegian transmission system operator, see www.statnett.no/en.

⁴ www.nordpoolspot.com.

A fundamental challenge for market participants in multiple markets, is how to optimally allocate volumes to the different markets. Bidding decisions for multiple, sequential electricity markets have been studied in a small number of papers, all seen from the perspective of a power producer. A literature review regarding this topic is given in Ref. [15]. It concludes that the optimal bidding strategy is found when all subsequent markets are taken into account when bids into the first market are decided. First, they review the bidding models, all covering a day-ahead market in different combinations with intraday, balancing and ancillary services markets ([16–20]). *Coordinated bidding* is the term they use when taking subsequent markets into account, while the contrary is denoted *separate bidding*. Just a few studies quantify the gain from coordinated bidding. Although these figures are not very high (0,1–2%), the gain is expected to increase with increasing price differences between the markets [16].

The problem under consideration in this paper has many similarities with the multi-market bidding studies referenced above. We also use the concept of coordinated bidding. However, our focal entity is not a power producer, but a demand side flexibility aggregator. To our knowledge this has not been covered before. Contrary to the studies above, we also include the OM, where capacity is reserved for later use in FM.

Our starting point is the previous work [21], where we developed a bidding and scheduling model for day-ahead market participation for an energy aggregator. The main objective for the aggregator was to minimize expected costs for supplying electricity to a set of prosumers, while dispatching flexible energy units. The model was formulated as a two-stage stochastic mixed integer program, where the uncertain parameters were represented in scenarios. In the current paper there are three major extensions. We now focus on flexibility (up- and down-regulation) explicitly. Instead of trading in one, single market, now we cover trading in three different markets. The problem is extended from a two-stage to a multi-stage problem.

The contribution from this article is four-fold:

- We develop a mixed integer multi-stage stochastic programming model for coordinated bidding to determine optimal bidding strategies for a flexibility aggregator participating in three sequential markets, including a market for reservation of capacity
- We model explicitly the information revelation process, and take into account that prices may realize differently from the scenarios
- To ensure technically feasible solutions, we put effort into modelling the flexibility units properly to capture physical and economic constraints in the underlying, physical systems
- We perform a realistic case-study based on 4 industrial companies and one aggregator including a quantification and discussion of the value of flexibility and the value of aggregation

The remainder of the paper is organized as follows: Chapter 2 outlines the problem, including descriptions of the trading process and the information structure. The mathematical formulations are presented in Chapter 3, while Chapter 4 contains the case study.

2. Problem description

2.1. Flexibility and market design

Let a flexibility aggregator manage a portfolio of flexibility units on behalf of a set of flexibility vendors. The flexibility aggregator's objective is to maximize the profit from the portfolio by trading in a set of markets. Each flexibility vendor has at least one flexibility

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