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Extending the bidding format to promote demand response

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HIGHLIGHTS

- Three new bid types are proposed to enrich demand-side participation.
- Time value of electricity demand can be clearly conveyed to central dispatcher.
- The extended format preserves market efficiency and incentive compatibility.
- Energy storage is most effective to neutralize price volatility, with a limitation.

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ABSTRACT

We propose an extended bidding structure to allow more realistic demand characteristics and behaviors to be expressed via flexible bids. In today's ISO-run energy markets, demand bid formats are all separable over time. However, a significant and growing segment of demand can be shifted across time and therefore has no way to bid its true valuation of consumption. We propose additional bid types that allow deferrable, adjustable and storage-type loads to better express their value, and thus elicit demand response in the most natural way – via direct participation in the market. We show that the additional bid types are easily incorporated into the existing market with no technological barrier and that they preserve the market's efficiency and incentive-compatibility properties. Using real market data, we give a numerical demonstration that the extended bid format could substantially increase social welfare, and also present additional insight on storage expansion scenarios.

1. Introduction

Sufficient demand-side participation is critical to the success of deregulated markets, since the marginal pricing and social welfare maximizing principles underlying their design are predicated on bid-based, competitive participation of both suppliers and consumers (Wellinghoff and Morenoff, 2007). However, reality has shown that the demand side lacks the ability to participate in the market comparably to the supply side, and exhibits significant unexpressed elasticity, resulting in inefficient market outcomes, exacerbating oligopoly power, and distorting long term investment incentives. There are two main causes. First, not all consumers are able to independently value the electricity ex ante (before the market clearing price is known) so as to place meaningful price-quantity bids on the market (Kirschen, 2003). This is inherent to the nature of electric energy, as most people regard electricity as an essential and non-substitutable commodity. Second, the bidding system does not provide a mechanism as an alternative to the price-quantity bid format for consumers to express their willingness to adjust consumption, particularly in response to price signals. Demand response (DR) is when a consumer modifies her usage behavior to account for price variations. For instance, if the consumer knows a priori that the price is high in some hours of the day and low in other hours of the day, she could reschedule usage to minimize the total cost (Schweppe et al., 1988). Incorporating changes in the market rules to induce demand response and encourage demand-side participation has garnered much recent attention from policy makers, practitioners and researchers.

Demand response resources are treated similarly to a generation resource by many ISO/RTO's programs. For example, DR providers can specify operating requirements such as a minimum

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curtailment period and DR initialization cost. Energy bids are taken on a similar basis. Almost all ISO/RTOs in north America take demand-side energy bids exclusively in two forms[1]: (1) fixed, specified by a quantity in MWh, and (2) price-sensitive (or elastic), specified by a number of price-quantity pairs. These bids make the consumer act as a price-taker, or force her to provide an explicit demand curve. Kirschen (2003) notes that a normal consumer, and subsequently her wholesale market representative, e.g. load serving entity (LSE), are unable to estimate such curves accurately.

This paper proposes an extended bidding structure to encourage more demand-side market participation. The extended format enriches the forms of demand-side participation, promotes a broader frontier for load dispatchability and yet preserves the theoretical properties of the current market design philosophy, such as economic efficiency and incentive compatibility (Stoft, 2002).

1.1. Market model: theory and reality

While the specific formats proposed in this paper focus on the demand side, the structure can be applied to both sides of the market (e.g. a hydro generator may have time-shiftable supply needs). In the abstract form, each market participant k has a benefit function $f_k(x_k)$ and operating constraint $x_k \in X_k$, where $x_k = [x_{k,1}, \ldots, x_{k,T}]^\top$ is the energy consumption/supply schedule. The participant's optimal response to the market price p is

$$\max_{x_k \in X_k} \quad f_k(x_k) - x_k^\top p \tag{1}$$

The solution $x_k(p) = [x_{k,t}(p)]$ determines the schedule of supply or demand across all times $t = 1, \ldots, T$. Note that time dimension is embedded in the vectors x_k and p, so all kinds of intertemporal relations can be expressed in the objective function as well as in the constraint X_k.

In the bid based central dispatch mechanism, each participant k simply informs (via bidding) the dispatcher its $f_k(\cdot)$ and X_k, and the central auctioneer (ISO/RTO) maximizes the social welfare by solving

$$\max_{x} \quad \sum_k f_k(x_k) \tag{2}$$

$$\text{s. t} \quad \sum_k x_k = 0 \ (\perp p) \tag{3}$$

$$x_k \in X_k, \quad \forall\, k \tag{4}$$

and using this model to set the market clearing prices. Eq. (3) says that the net power surplus (generation minus consumption) is zero and the market price p is the shadow price corresponding to this power balance equation. Note that each market participant has their own optimal response to these prices. If a dispatch and pricing model is designed such that the central dispatch solution with the accompanying prices coincides with the market participants' optimal response to these prices, then competitive participants have every reason to bid their true parameters,[2,3] thus the model is incentive compatible. If the central dispatcher does not have accurate input $f_k(\cdot)$ and X_k from market participants about their true valuation of electricity, there is no way for the dispatcher to maximize the social welfare. In other words, one cannot maximize something without accurately measuring it.

The existing market model (where only fixed and elastic bids are allowed) is a special case of (1), having two specialties:

1. the value function f is separable across time, thus restricted to the form

$$f_k(x_k) = \sum_t f_{k,t}(x_{k,t});$$

2. the constraint set X_k of a consumer k is also separable across time, i.e.,

$$X_k = \prod_t X_{k,t}.$$

These restrictions hinder efficient market participation. For example, a consumer with shiftable demand has no way to express this shiftability in a bid and may have to predict the price path so as to approximate this feature using time-separable price-quantity bids. The prediction and approximation are error-prone and most likely to lead to suboptimal outcomes.

In contrast, the general (and well-established) model above avoids such problems but still retains nice theoretical properties. As long as each $f_k(\cdot)$ is a concave function, and each X_k is a convex set, the important economic design properties will hold and the model will remain easy to solve. The key point of this paper is to propose new mechanisms for bidding that allow for more complex f_k and X_k to be described in natural ways. In addition to fixed and elastic demand, we identify three additional types of demand, namely, shiftable, adjustable and arbitrage. We will formulate the basic characteristics and model the behavior of each type of demand. Fig. 1 illustrates a structural overview of our work. Note that all of our formulations are in the form given by (1) for particular choices of x_k, X_k and f_k, and the new types are not separable across time. This amounts to a policy change that enhances the types of load that can be bid into the market.

1.2. Policy and literature review

Broadly, a more responsive demand-side is desired from both economic and reliability standpoints. However, the existing policy on demand response (FERC, 2011), which requires ISO/RTOs to compensate curtailed energy consumption at the LMP, sends wrong economic incentives to market participants.[4] A full-LMP compensation gives the DR providers, presumably retail customers who would normally be charged at the retail price G for consumption, both the LMP and the savings from not consuming, totaling LMP+G, which amounts to an uneconomic double-payment, see Chao (2010, 2011) and Hogan (2009, 2010, 2012). Within the monetary compensation framework, ISO/RTOs have made various localization efforts to preserve the economic efficiency of demand response. For example, ERCOT has implemented an “LMP minus proxy G” approach to avoid the double-payment problem, where G is a proxy for the purchase price or contract price that is

[1] ISO/RTOs surveyed include: ISO New England, Midwest ISO, PJM RTO, New York ISO, California ISO and ERCOT. Note that fixed demand bids include the load estimates made by forecast procedures, such as ERCOT's load profiling process.

[2] Note that the bidding behavior of a *competitive* participant is assumed to have negligible effect on the market price. Suppose that a competitive participant bids differently from its true cost, then under the same market price her dispatch order will be different from, hence worse than, her optimal choice.

[3] Also note that large participants' strategic bidding behavior does exist and poses a real concern for market designers and system operators. However, the bid-based two-sided market design of today's ISO-run energy markets, as well as the economic justification of its superiority over the vertically intergraded utility model, is based on the *competitiveness* assumption. We therefore inherit this assumption in our discussion of the theoretical market design.

[4] The FERC Order No. 745 was issued by the Federal Energy Regulatory Commission (FERC) on March 15, 2011 and was vacated by the U.S. Court of Appeals for the District of Columbia Circuit on May 23, 2014. On May 4, 2015, the U.S. Supreme Court announced that it will hear an appeal by FERC. The hearing is still impending by press time.