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Strategic bidding for electricity supply in a day-ahead energy market

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Abstract

The problem of building optimal bidding strategies for competitive suppliers in a day-ahead energy market is addressed in this paper. It is assumed that each supplier bids 24 linear energy supply functions, one for each hour, into the day-ahead energy market, and the market is cleared separately and simultaneously for all the delivery hours. Each supplier makes decisions on unit commitment and chooses the coefficients in the linear energy supply functions to maximize total benefits in the schedule day, subject to expectations about how rival suppliers will bid. Two different bidding schemes, namely 'maximum hourly-benefit bidding strategies' and 'minimum stable output bidding strategies', have been suggested for each hour, and based on these two schemes an overall bidding strategy in the day-ahead market can then be developed. Stochastic optimization models are first developed to describe these two different bidding schemes and a genetic algorithm based method is then presented to develop an overall bidding strategy for the day-ahead market. A numerical example is utilized to illustrate the essential features of the method. © 2001 Published by Elsevier Science B.V.

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1. Introduction

Ideally, the market structure and management mechanisms, or rules, in an electricity market should be sufficiently well designed and competition among participants sufficiently vigorous to direct the operation of the market towards maximizing social welfare. However, the emergent electricity market structure is more akin to oligopoly than perfect market competition. This is due to special features of the electricity supply industry such as, a limited number of producers, large investment size (barrier to entry), transmission constraints which isolate consumers from effective reach of many generators, and transmission losses which discourage consumers from purchasing power from distant suppliers.

One of the main objectives of investigating strategic bidding is to identify the potential for abuse of market power through loopholes that can be exploited in the market structure. Although a variety of electricity market restructuring models have been proposed, the day-ahead pool-type market is of greatest interest, and is the subject of this paper. It is obvious that development of bidding strategies should be based on the market model and activity rules, especially, auction rules and bidding protocols. Depending on different market designs, the energy bids may include several price components (multipart bid) or a single price component (single-part bid) [1]. A multipart bid may include separate prices for unit startup, no-load operation, and energy, and an example of this kind of bidding protocol is the England–Wales electricity market. A single-part bid would offer an energy price inclusive of other fixed or variable costs, as is the case in the California electricity market. In either case, the energy bid may include several energy price segments depending on the amount of energy supply (e.g. a separate price for each block of energy from the same unit or portfolio of units). In the case where the market

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design is based on single-part bids, a simple market clearing process based on the intersection of supply and demand bid curves may be sufficient to determine the winning bids and schedules for each hour. On the other hand, if the market design is based on multipart bids, a unit commitment program may be needed by the market operator to clear the market.

This paper aims to develop bidding strategies for power suppliers participating in the California-type day-ahead energy market [1,2], in which the single-part bid for energy is required for each of the 24 h in the schedule day. Before proceeding to deal with this problem, a brief survey on the state-of-the-art of research on the strategic bidding in electricity markets is presented.

The strategic bidding problem for competitive power suppliers was addressed for the first time in Ref. [3], and a conceptual optimal bidding model and a dynamic programming based solution method developed, for England–Wales type electricity markets, in which each supplier is required to bid a fixed price for each block of generation. System demand variations and unit commitment costs were considered in the model. In Ref. [4], an analytical formulation for building the optimal bidding strategy in England–Wales type electricity markets was developed under an assumption that the market clearing price is independent of the bid of any supplier. In Ref. [5], a simple suboptimal bidding strategy was proposed for the situation when two buyers (utilities) are competing for a single block of energy supply but it cannot be directly extended to the general case with multiple suppliers. In Ref. [6], an asynchronous or 'sequential' bidding scheme based on a radial basis function neural network was suggested which allows the suppliers to revise their bids once more. In Ref. [7], this problem was described as a two-level optimization procedure. At the top level a centralized economic dispatch is employed to determine the market clearing price, the production and demand levels of all generators and consumers, and at the lower level a self-unit commitment based on a parametric dynamic programming with an embedded variable bidding parameter is used by each supplier to determine a profitable bid.

Many additional studies were reported in 1999. In Ref. [8], a dynamic model of strategic bidding for the situation with three power suppliers was proposed by utilizing the historical and current market clearing prices. This model is heuristic in principle, and is not directly applicable to the general case with more than three suppliers. In Ref. [9], a linear supply function model was presented to investigate strategic bidding behavior, and to illustrate some of the ways market power can be exercised. A similar linear supply/demand function model was employed in Ref. [10] to build optimal bidding strategies for competitive suppliers with an objective of maximizing social welfare. Moreover, a payment rule named 'multiple-commodity second price auction' is compared with the popular uniform price rule, and it is shown by simulation results that the suppliers have a larger incentive to bid at marginal costs if the former rule rather than the latter one is utilized. In Ref. [11], a two-level optimization procedure for building bidding strategies was presented in which market participants try to maximize their profits under the constraints that the independent system operator (ISO) determines their dispatches and market price utilizing a transparent optimal power flow (OPF) program with an objective of maximizing social welfare. It is assumed that each participant has an estimated value for the bid from each of the other participants. In Ref. [12], a bidding strategy for suppliers in the uniform price clearing auction is developed by estimating the probability of winning below and on the margin, and a simple bidding model is then obtained under some simplified assumptions. In Ref. [13], a method is presented for optimization-based bidding and self-scheduling decisions from the viewpoint of a utility which can bid part of its energy to the market and self-schedule the rest, as is the case in New England. In Ref. [14], intelligent trading agents, such as genetic algorithm, genetic programming and finite state automata, are utilized for developing adaptive and evolutionary bidding strategies.

Up to now, research work on strategic bidding has been concerned with one-period auctions, only little has been done on multiple-period auctions. As for the California-type day-ahead energy market managed by a power exchange (PX), to the best of our knowledge, the existing publications are limited to one-period auctions. In the single-part bid a supplier must internalize all involved costs, such as start-up cost, in building its bidding strategy, i.e. the relationship between the price and the energy supply. A unit commitment program is essential for the supplier. Ignorance of the unit's start-up costs, operating constraints and inter-temporal dependences will fail to maximize the total benefits in developing an overall bidding strategy for the day-ahead market.

It is supposed that the suppliers have the freedom to price away from their costs, and they bid 24 linear energy supply functions separately, one for each hour, into the day-ahead energy market. Each supplier needs to solve two problems, i.e. how to determine the unit commitment status and how to choose the coefficients in the 24 energy supply (bid) functions, one for each hour in the schedule day, so as to maximize total benefits. These two problems cannot be dealt with separately and must be properly coordinated.