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Analysis of equilibrium about bidding strategy of suppliers with future contracts

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Abstract

In this paper, the supply function model is employed to simulate the bidding strategy of suppliers in the power pool, and models of the supply function with future contracts are presented. It is proved that only one of the parameters between slope and intercept of the bidding curve is an independent variable in order to achieve definite equilibrium. In the meantime, the equilibria of the bidding strategy about suppliers are studied when different intercepts of the bidding curve are chosen. Some examples are employed to study the Nash equilibrium strategies of suppliers with different future contracts in various bidding strategy models. The results show that the equilibria are different in different bidding strategy models, but the future contracts can effectively make spot prices decrease in all the models.

Keywords: Supply function model; Bidding strategy; Bidding curve; Future contracts; Equilibrium

1. Introduction

The electric power industry worldwide is experiencing unprecedented restructuring from the traditional integrated regulation monopoly to a competitive power market. The object of deregulation is to introduce a competition mechanism into the power market and provide incentives for efficient operation of the power industry, eventually reducing the market price. The ideal market is a perfect competitive market in which participants bid their marginal cost into the market. Consequently, the market price is low in this kind of market. However, the electricity market is different from other merchandise markets. In the power market, only a few suppliers can provide power services in some geographic region. This is due to the restriction of some factors, such as large investment scale, small demand elasticity, transmission constraints and no largely storable electricity. Consequently, the actual power market is more close to an oligopolistic market in which the suppliers can achieve maximum profit through strategic bidding. That means that the generation companies possess market power, which is harmful to the operation of the power system and will make electricity price far higher than the marginal cost of the power market. One famous example is the electricity crisis of California of America in the summer 2000, which made the electricity price far above competitive levels. So, it is meaningful to study the bidding strategy of suppliers.

Generally speaking, there are basically three ways for a supplier to develop an optimal bidding strategy [1]. The first one relies on estimation of the market clearing price (MCP) in the next trading period, the second one is based on estimation of the bidding behavior of rival participants and the third one is game theory based. The models of bidding strategy of suppliers based on game theory used in the power market are mainly Cournot, Bertrand and the supply function model [2]. Among these models, both the Cournot and supply function models are widely studied. Probability theory is employed to study the bidding strategy of suppliers based on the supply function model in Refs. [3,4], where the bidding coefficients of rival participants are assumed to obey a joint normal distribution. In

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Ref. [5], a conjectured supply function is utilized to simulate the bidding strategy of suppliers. In Ref. [6], a supply function model whose slope and intercept of the bidding curve vary with the same scale is employed to analyze the bidding strategy of suppliers, where the influence of contracts for difference CFDs [7] (CFDs means that if the spot price rises above the strike price, which is the price level at which the contract can be called, suppliers compensate retailers for the difference, but if the spot price falls below the strike price, then the retailers compensate suppliers for the difference) on market equilibrium is considered. In Ref. [8], the concept of virtual rival and the method of parameter estimation are introduced to study the bidding strategy of suppliers based on game theory, where the slope and intercept of the bidding curve is also assumed to vary with the same scale.

Forward contracts are one of the efficient means for risk management, and it is applied in the power market of many countries. The power pool will plan the electricity of suppliers according to the market rules, the bidding price of suppliers and forward contracts while there are forward contracts between suppliers and buyers. The bidding strategy of suppliers will vary with the forward contracts to achieve maximum profit. In this paper, a supply function model is used to simulate the bidding strategy of suppliers in a power pool. Firstly, a supply function model with forward contracts is presented. Accordingly, it is proved that only one of the parameters between the slope and intercept of the bidding curve can be strategy variable in order to achieve definite equilibrium (the Nash equilibrium is a strategy profile in which each player's part is as good a response to what the others are meant to do as any other strategy available to that player [9]). Secondly, the equilibria of the market are studied when different intercepts of the bidding curve are chosen. Finally, the effect of different future contracts on the equilibrium strategies of suppliers in various bidding strategy models is analyzed. Besides, the bidding strategies are also studied while generation constraints are active.

2. Supply function equilibrium model with forward contracts

It is supposed that the inverse demand function is a linear function, that is

$$p = r - s\sum_{i=1}^{N} q_i \tag{1}$$

where p is market price, r and s are the intercept and slope of the inverse demand function, respectively, q_i is the generation of the supplier i and N is the number of suppliers.

Eq. (1) can be transformed into the electricity demand function,

$$\sum_{i=1}^{N} q_i = q_{\max} - lp \tag{2}$$

where $q_{\max} = \frac{r}{s}$, $l = \frac{1}{s}$.

The bidding curve of the supplier is assumed as a linear function,

$$p_i = \alpha_i q_i + \beta_i \tag{3}$$

where α_i and β_i are the intercept and slope of the bidding curve, respectively, both of which are larger than zero, and $i = 1, \ldots, N$.

The electricity price is assumed to clear at the uniform price in the power pool, and then, the generations of the suppliers are calculated according to Eqs. (2) and (3).

If the forward contracts is f_i while the dealing price is λ_i, the equilibrium state of the suppliers can be obtained by maximizing an individual profit function of each supplier.

$$\max_{q_i} \pi_i = p(q_i - f_i) + \lambda_i f_i - c_i(q_i)$$
$$st\ q_{i\,\min} \leqslant q_i \leqslant q_{i\,\max} \quad (i = 1, \ldots N) \tag{4}$$

Without loss of generality, the cost function of a supplier is assumed to be a quadratic function of active power generation. That is:

$$c_i(q_i) = \frac{1}{2}a_i q_i^2 + b_i q_i + c_i \quad (i = 1, \ldots, N) \tag{5}$$

Then, the generation of supplier i is

$$q_i = (p - \beta_i)x_i \tag{6}$$

where $x_i = \frac{1}{\alpha_i}$.

Correspondingly, the system marginal price is

$$p = \frac{q_{\max} + \sum_{j=1}^{N} \beta_j x_j}{l + \sum_{j=1}^{N} x_j} \tag{7}$$

If both the intercept and slope of the bidding curve are chosen to be independent strategy variables by the supplier, the maximum profit of supplier i can be achieved when the following differential equation is satisfied

$$\frac{\partial \pi_i}{\partial x_i} = \frac{\partial p}{\partial x_i}(q_i - f_i) + p\frac{\partial q_i}{\partial x_i} - (a_i q_i + b_i)\frac{\partial q_i}{\partial x_i} = 0 \tag{8}$$

$$\begin{aligned}\frac{\partial \pi_i}{\partial \beta_i} &= \frac{\partial p}{\partial \beta_i}(q_i - f_i) + p\frac{\partial q_i}{\partial \beta_i} - (a_i q_i + b_i)\frac{\partial q_i}{\partial \beta_i}\\ &= \frac{x_i}{\beta_i - p}\left[\frac{\partial p}{\partial x_i}(q_i - f_i) + (p - a_i q_i - b_i)\frac{\partial q_i}{\partial x_i}\right]\\ &= \frac{x_i}{\beta_i - p}\frac{\partial \pi_i}{\partial x_i} = 0\end{aligned} \tag{9}$$

Eqs. (8) and (9) show that the intercept and slope of the bidding curve are not independent. The $2N$ variables, x_i and β_i, need to be calculated by means of N equations, so there exists an infinite number of equilibrium states. That means only one of the parameters between the intercept and slope of the bidding curve is independent in order to achieve a definite equilibrium.

If the slope of the bidding curve is chosen to be the strategy variable by supplier i, Eqs. (6)–(8) yield the following optimal reaction function of supplier i