Ming ZENG, Ku er ban·Nu er mai mai TI, Hongzhi LIU, Song XUE, Lilin PENG

School of Economics and Management , North China Electric Power University, Beijing 102206 P. R. China

Research on Optimal Bidding Strategies for Gas-Fired Distributed Generation in a Day-Ahead Electricity Market with Bilateral Contracts

Abstract*. In regard to the current development of gas-fired DG, we proposed a bidding mechanism for the integration of DG into the grid that includes contract transaction, day-ahead trading and real-time trading. Considering the impact of bilateral contracts and unit commitments on the day-ahead electricity market, a day-ahead market bidding model of gas-fired distributed generation was built. Using a numerical example, the impact of bilateral contracts on the generation output and the profit of distributed generators were analysed in detail for a perfect competitive market and an imperfect competitive market. The results of the proposed method show that a generator can support optimal bidding strategies to maximise its total profit when bilateral contracts and unit commitments are considered; these results are positive for the recovery of investment costs recovery and for the verification of the rationality and feasibility of the proposed model*

Streszczenie. *W artykule autorzy przedstawiają mechanizm licytacji, na potrzeby podłączania generatorów gazowych w systemie rozproszonych źródeł energii do sieci elektroenergetycznej. Mechanizm obejmuje zawieranie umów, handel i negocjacje na żywo oraz pojęcie „rynku dnia następnego”. Poprzez analizę numeryczną zbadano wpływ umów dwustronnych na zyski z wytwarzania energii na rynku idealnie i nieidealnie konkurencyjnym. Przedstawiono wyniki potwierdzające skuteczność działania mechanizmu. (****Badania optymalnych strategii licytacji na potrzeby energetyki gazowej w systemie rozproszonych źródeł energii – umowy dwustronne na rynku „dnia następnego”****).*

Keywords: Gas-fired Distributed Generation, Bidding Mechanism, Day-ahead Electricity Market, Bilateral Contract, Unit Commitment, Bidding Strategy.

Słowa kluczowe: kogeneracja rozproszona gazowa, mechanizm licytacji, rynek dnia następnego, umowy dwustronne, zobowiązanie jednostki, strategia licytacji.

Introduction

China has already put forward in the Twelfth Five-Year Plan to promote the revolution of energy production and energy consumption and to construct a safe, stable, economic and clean modern energy industry system. The existing research mainly provides strategies for Gencos setting bidding prices by establishing the bidding models under various constraints [1-3]. However, studies focusing on DG bidding strategies under recent situations are rare. Based on the existing studies, and by combining the development status of gas-fired DG and the corresponding encouragement policies in China, this paper proposes a bidding mechanism for the integration of DG into grid by first. Then, by considering the impact of bilateral contracts and unit commitments on the day-ahead electricity market, a day-ahead market bidding model of gas-fired distributed generation was built. Finally, the simulations was used to analyse the impact of bilateral contracts on the generation output and the profit of distributed generators under a perfect/imperfect competitive market.

The Gas-Fired DG Bidding Mechanism

The corresponding operation cost can be recovered by sharing the profit of DG. The basic process of price bidding for transaction is shown in Figure 1.

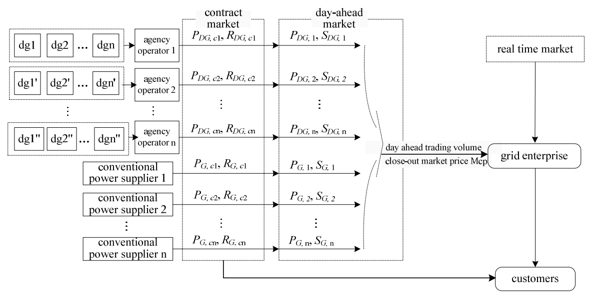

Fig.1: The progress of DG bidding.

Day-Ahead Market Bidding Model of Gas-Fired DG Units

1. The Day-Ahead Market Bidding Model of Gencos.

The power exchange centre determines the Mcp and the hourly power generation output, according to the quoted price submitted by Gencos and to the load forecast. Assuming that the linear bidding function submitted by each Genco is $S_i(P_i) = a_i+b_iP_i$. The Mcp, the hourly power generation output and the hourly profit of each Genco can be found according to formulas (1) – (3):

$$Mcp = [Q + \sum_{i=1}^{n}\frac{a_i}{b_i}]/[\sum_{i=1}^{n}\frac{1}{b_i}] \tag{1}$$

$$F_i = Mcp \cdot P_i - C(P_i) \tag{2}$$

$$C(P_i) = \alpha P_i^2 + \beta P_i + \gamma \tag{3}$$

With constrains: $P_i=(Mcp-a_i)/b_i$, $P_{i,min} \leqslant P_i \leqslant P_{i,max}$, $\Sigma P_i=Q$

In these equations, Mcp is the market clearing price; Q is the day-ahead load forecast, Pi is the power generation output of Genco i; a_i and b_i are the bidding coefficients of the quoted price function. and Fi is the profit of Genco i; $C(Pi)$ is the cost function of Genco i.

If Genco i signs a bilateral contract with the grid companies or the power consumers in electricity market, and among them the trading volume is P_c and the trading price is R_c, then the profit function of Genco i becomes

$$R_i = Mcp \cdot P_i + R_c P_c - C(P_i + P_c) \tag{4}$$

The total profit of Genco i during operating period can be expressed as formula (5) and constrained by formula (9):

$$\max \Phi = \sum_{t=1}^{24}[\mu_t R_i^{(t)} - D_i^{(t)}\mu_t(1-\mu_{t-1})] \tag{5}$$

$$\mu_t = \begin{cases} 1 & \text{if} \quad t_{on} > t_{up} \\ 0 & \text{if} \quad t_{off} > t_{down} \\ 0 \text{ or } 1 & \text{others} \end{cases} \tag{6}$$

In these equations, D is the setup cost, μ_t is the state of Genco i (1 denotes operating, 0 denotes off-the-line), t_{on} is the duration time of operation of Genco i, t_{off} is the outage time of Genco i, t_{up} is the minimum operating time, and t_{down} is the minimum outage time. Usually, the starting and stopping costs of a DG are far lower than that of general power generation, and the limits resulting from operating time and outage time of DG are also lower.

2. Model Solution.

The first step, the operating state and bidding strategy of Genco i can be determined, taking either formula (2) or (4) as target function, as shown by formulas (7). This programming problem can be solved by a Lagrange relaxation algorithm and Kuhn-Tucker condition [5].

$$\max R_i(a_i, b_i, P_i) = R_c P_c + (a_i + b_i P_i) P_i - C_i(P_i + P_c) \tag{7}$$

The second step, the operating state of Genco *i* is checked. If it satisfies the constraints of unit commitment, then the bidding strategy is optimal for the day-ahead market, the Genco *i* should maintain all-day operating, and the computational process should be over. Otherwise, the third step should be conducted.

The third step, adjusting the operating state of Genco *i* to realise its maximum profit within 24 hours. If the Genco *i* has to keep operating because of the indemnificatory constraints (such as the minimum operating time), then the quoted price coefficient can be changed and the bidding power generation output can be reduced to ensure that Genco *i* obtains the power dispatch of power exchange centre.

Simulation Analysis

In the network structure simulation analysis of IEEE-30, it is assumed that there are 6 Gencos in an area (G1, G2, G3 are conventional Gencos, DG3, DG4, DG5 are agency operators of gas-fired DG) and that the relevant data and corresponding generation output constraints of the production cost function of Gencos are set to the values shown in Table 1.

Table 1: Data for Gencos.

Gencos	α	β	γ	Pmin(MW)	Pmax(MW)
G1	0.0054	2.7	74	50	200
G2	0.0056	2.8	76	50	200
G3	0.0060	3.0	95	50	200
DG4	0.0065	3.25	15	10	50
DG5	0.0060	3.0	10	5	15
DG6	0.0060	3.0	10	5	15

In the contract trading market, the contract power generation output and the power price of Gencos are as set to the values shown in Table 2. This paper considers two situations: situation 1 (S1), in which there is only a pool transaction mode in electricity market; and situation 2 (S2), in which there are two kinds of transaction modes in electricity market, the pool transaction mode and the bilateral contract transaction mode. The forecasted day-ahead electricity market load published by power exchange centre is displayed in Figure 2.

Table 2: Data for the bilateral contract market

Gencos	Pc(MW)	Rc(￥/kWh)	T(hour)
2	15	0.39	24
3	15	0.39	24
4	5、10、15	0.39	24
5	5	0.39	24

Under this market environment, Gencos offer prices according to their marginal cost, as shown in Figure 3. The analyses for S1 and S2 are conducted simultaneously. Assuming that DG4 has 3 kinds of contract power generation output (5 MW, 10 MW and 15 MW), the impact on the Mcp, the power generation output and the profit of DG4 in the bilateral contract is analysed. The results of the model are shown in Figures 4-6.

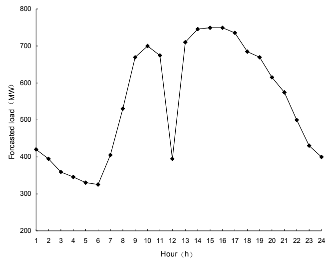

Figure 2: The forecasting curve of the daily load

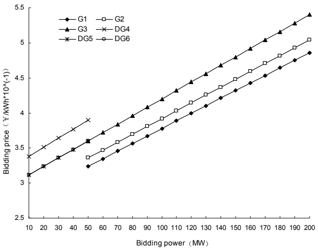

Figure 3: The bidding curves of Gencos

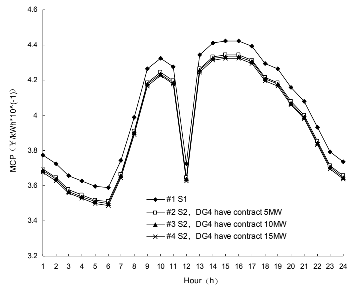

Fig. 4: Mcp

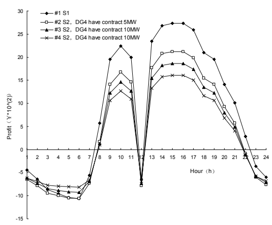

Fig. 5: Hourly profit for DG4 output in day-ahead market

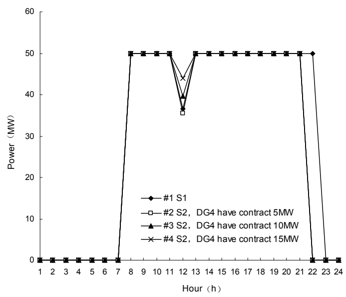

Fig. 6. Generation of DG$

Figure 4 shows that the Mcp in S2 is less than that in S1; in addition, the figure shows that the DG4 bilateral contract (5 MW, 10 MW, 15 MW) in S2 has nothing to do with the Mcp. The large differences between the Mcp and the contract power price in hours 1-6, hours 9-11 and hours 14-24 that is observed mean that the contract power price and that contract power quantity is unreasonably matched during this time period. Figure 5 describes the impact of DG4's bilateral contract on the day-ahead market profit. Comparing these two situations, the profit is decreasing in hours 8-11 and hours 13-21 as the contract power quantity is increasing. In S2, when the bilateral contract power quantities are either 5 MW or 10 MW, the profit of DG4 is negative because the Mcp is too small to make up the fixed operating cost caused by the low power-generation output during hours 1-7, hour 12 and hours 22-24. The quoted prices curve for power generation producers is displayed in Figure 7. Meanwhile, it is assumed that the bilateral contract power quantity remains constant and that the bilateral contract power price is changed to 0.43￥/kWh. In the imperfectly competitive market, the average price of the Mcp is 0.443￥/kWh. The calculations of the hourly power generation output and profit of DG4 are shown in Figures 8 and 10.

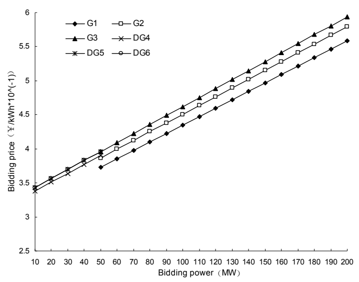

Fig. 7: The bidding curves of Gencos.

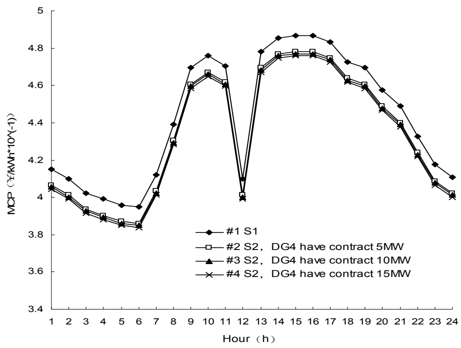

Figure 8: Mcp.

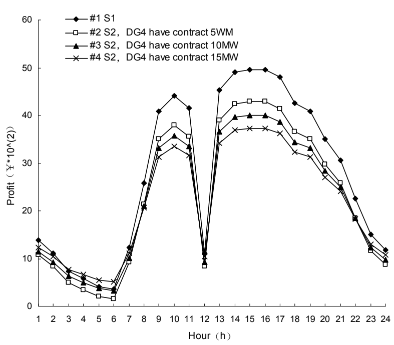

Fig. 9: Hourly profit for DG4 in day-ahead market

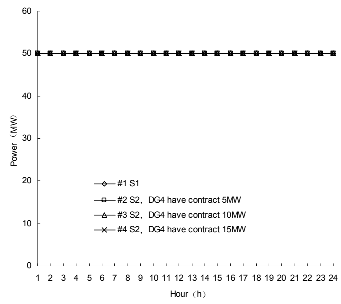

Fig. 10: Generation output of DG4

In the imperfectly competitive market, the bidding prices of G1 and G2 are 15% higher than the marginal costs, and the bidding prices of G3, DG5 and DG6 are 10% higher than the marginal costs. DG4 improves the bidding price by adjusting its quoted price coefficient. The bidding price will increase along with the increase of bilateral contract power quantity. Under this situation, the improvement of the bidding price will influence Mcp shown as Figure 11.

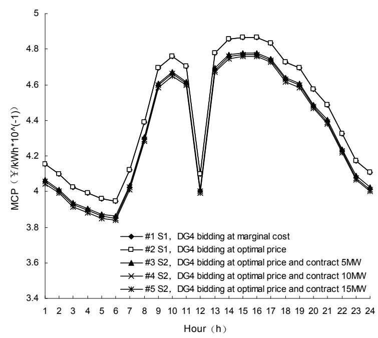

Fig. 11: *Mcp*

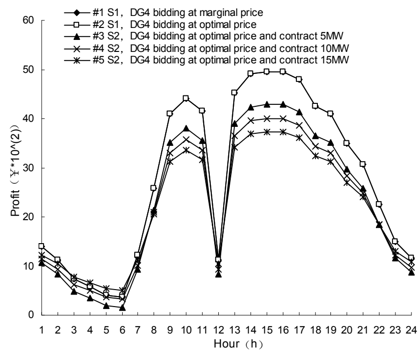

Fig. 12: Hourly profit for DG4 in day-ahead market

Figures 12 and 13 describe the profit and power generation output, respectively, of DG4 under the different situations. As is shown in Figure 11, DG4 submits its bidding price at the marginal price, the Mcp is same as DG4 submitting its optimal bidding price. Furthermore, the change of bilateral contract power quantity in S2 has no impact on Mcp. Generally, when bilateral trading exists in the market, the Mcp is effectively reduced. Figure 12 describes the impact of DG4's optimal bidding price strategy on its profit. Under S1, the profit is same when the bidding price of DG4 is either the marginal cost or the optimal bidding price. Under S2, in trading hours 1-7 the bilateral contract trading power price of DG4 is lower than Mcp and the profit of DG4 increases with the increase of contract power quantity. However, under the same situation in trading hours 8-11 and 13-22, the profit of DG4 decreases with the increase in contract power quantity because the bilateral contract trading power price is lower than Mcp. Through calculation, the total profit of DG4 are 66144.26 $yuan$, 66144.26 $yuan$, 55286.28 $yuan$, 53771.85 $yuan$ and 52516.97 $yuan$ each day under S1 and S2. As observed from Figure 12, the profit is positive. DG4 can obtain continuous dispatching under each situation with no need for constraining the state of the unit commitment.

Conclusions

This paper examined the optimal bidding strategy of day-ahead electricity market for power generation producers with bilateral contracts. It also need to be pointed that, the gas-fired DG agency operators should consider the impact of bilateral contracts on their profit within reason and determine the contract power quantity and power price signed in the bilateral contract correctly. Meanwhile, the initial investment of gas-fired DG is often large, and the government should conduct financial subsidies for DG power generation producers (including the DG resource agencies) to ensure that investors recover their investments during the equipment life period. Furthermore, problems concerning DG power price subsidies, on-grid safety (especially for the fluctuant DG) and contract risk should be studied further.

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Authors: *prof. Ming Zeng, School of Economics and Management, North China Electric Power University, Beijing 102206, China, E-mail: zengmingbj@vip.sina.com; drKu er ban·Nu er mai mai ti, School of Economics and Management, North China Electric Power University, Beijing 102206, China, E-mail: nur188@sina.com; dr Hongzhi Liu, School of Economics and Management, North China Electric Power University, Beijing 102206, China, E-mail: feiyuezhi@126.com; dr Song Xue, School of Economics and Management, North China Electric Power University, Beijing 102206, China, E-mail: xuesongbjhd@163.com; dr Lilin Peng, School of Economics and Management, North China Electric Power University, Beijing 102206, China, E-mail: penglilin@ncepu.edu.cn.*