2001년도 대한전기학회 하계학술대회 논문집 2001.7.18-20

경쟁적 전력시장에서의 입찰 전략에 대한 연구

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A Study on Bidding Strategies in a Competitive Electricity Market

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Abstract - Power transactions are considered as noncooperative game in that participants compete each other to win the bidding game, and as cooperative game in that they have to cooperate to apply the result of bidding game to the physically interconnected power system. This paper applies both noncooperative and cooperative game theories in analyzing the entire process of power transaction.

1. INTRODUCTION

The models in a competitive electricity market can be categorized as Pool, Bilateral, and the hybrid of the two[1]. The paper chooses the Pool model to realize an open market situation. In the Pool model, generators offer and distributors bid to determine the market clearing price (spot price) in an incomplete information situation. In the process of offer and bid, the market players set up the bidding strategies based on the available information like a game. We, therefore, try to apply game theories to simulate and analyze the transactions in a power pool. The Nash bargaining scheme is employed in our study. In addition, transmission game is also incorporated into our analysis.

2. Power Transaction Game

2.1 Noncooperative Bidding Game

Competition in the restructured electricity market requires the market players to build a strategy to maximize their own profit, while cost minimization was the ultimate goal in vertically integrated utilities[2,3]. To analyze the behavior of a profit maximizing utility, we define the production cost function and the profit function as follows:

$$C_i = C_i(P_i) = a_i + b_i P_i + c_i P_i^2 \qquad (1)$$

$$PF_i = \rho_t P_i^{allocated} - C_i(P_i^{allocated}) \qquad (2)$$

where

ρ_t , denotes the system spot price at time t and,

$P_i^{allocated}$, the allocated power amount to utility i

In addition, the electricity demand responding to the spot price is assumed to be

$$D_t = D_0 - S\rho_t \; . \qquad (3)$$

For mathematical convenience, only two generators are assumed to play in the market. Then one might expect the following 3 cases.

$\rho_A > \rho_B$, or $\rho_A < \rho_B$, or $\rho_A = \rho_B$

i) $\rho_A > \rho_B$ or $\rho_A < \rho_B$

If $\rho_A > \rho_B$, then the market price, ρ_T , is determined as ρ_A, and the market demand at ρ_A is

$$D_t = D_0 - S\rho_A \; . \qquad (4)$$

Utility B becomes to have the optimal generation amount P_B^* by the condition $\partial PF_B / \partial P_B = 0$ maximizing its own profit. Utility A's allocated demand is the amount subtracting B's allocated demand from the entire system demand.

Consequently, the optimal bidding strategy of each utility A, B is given ;

A's strategy : (ρ_A^*, $P_A = D_t - P_B^*$).

B's strategy : ($\rho_B < \rho_A$, P_B^*).

ii) $\rho_A = \rho_B$

In this case, there exists no equilibrium point, because one utility can make more benefit by modifying its own bidding strategy.

2.2 Cooperative Nash Bargaining Game

We incorporate the transmission entity into our previous analysis in section 2.1. In this case, in order to reach an agreement on transactions, they need to negotiate for a flow pattern acceptable to both parties.

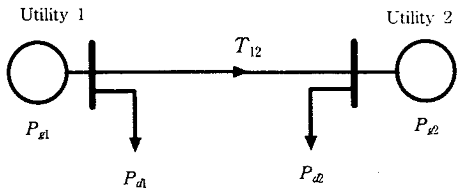

Fig. 1 2-bus 2-utility system

The generation schedule, (P_{g1}, P_{g2}), derived in section 2.1 is assumed to be applied to the power system(Fig 1). Then, we need to reformulate the problem to deal with the new situation. The Nash bargaining problem with transmission constraint can be described as eq.(5), provided that the transmission cost is equally divided into two utilities.

$$Max: R_1 \cdot R_2 \qquad (5)$$

where

$$R_1 = p_T T_{12} - C_1(P_{g1} + T_{12}) + C_1(P_{g1}) - 0.5 \times TC(T_{12})$$

$$R_2 = -p_T T_{12} - C_2(P_{g2} - T_{12}) + C_2(P_{g2}) - 0.5 \times TC(T_{12})$$

TC transmission cost

T_{12} transaction amount between two utilities

The first term in R_1 and R_2 is the payment for the transaction, and the second term is the change in the local operation cost owing to the transaction. The third term is the initial operation cost, and the fourth term is transmission cost allocated to each utility. Finally we obtain the equilibrium point (p_T^*, T_{12}^*).

3. CASE STUDY

This section demonstrates a case applicable to both noncooperative and cooperative game simultaneously (Fig.2). All the data is put in Table 1. The intermidiate and final solutions are summarized in Table 2, Table 3, and Table 4, respectively

Tab. 1 The Cost Coefficient of A,B

Player	Cost Coefficient			Gen. Limit	
	a_i	b_i	c_i	Min[MW]	Max[MW]
Utility A	0	6.0	0.22	10	250
Utility B	0	2.0	0.42	20	200

Tab. 2 The first equilibrium point

	A's best strategy	B's best strategy
ρ_A	·	98.03
(P_A, P_B)	(209 , ·)	(· , 94)
D_t	303	
(PF_A, PF_B)	(9624.45 , 5315.7)	

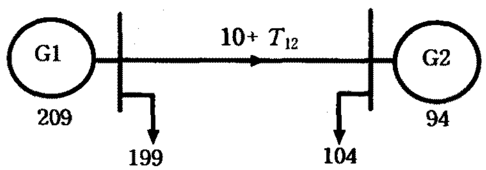

Fig. 2 The occurrence of T_{12}

		Gen. [MW]	Oper. Cost [$/h]	Savings [$/h]
Before Trans.	Util. 1	209.00	10863.82	-
	Util. 2	94.00	3899.12	-
After Trans.	Util. 1	233.00	13349.90	377.98
	Util. 2	70.00	2168.00	377.98
Transaction Power T_{12}			34.00(MW)	
Transaction Price			62.33($/MWh)	
Payment			2109.10($)	

Tab. 3 NBS Results

Tab. 4 The final equilibrium point

	A's best strategy	B's best strategy
ρ_A	·	98.03
(P_A, P_B)	(243 , ·)	(· , 60)
D_t	303	
(PF_A, PF_B)	(9462.33 , 5693.68)	

4. CONCLUSION

This paper suggests an approach to analyzing the power transactions in a competitive electricity market. First, a systematic application of a noncooperative game theory for the market participants who maximize the net profits is presented. Second, a Nash bargaining approach for a cooperative game incorporating the transmission constraint is introduced.

Our future work is to verify the applicability of the approach suggested in this paper to other market models and more complex system with n generators and buses. It is our ultimate goal to develop a market analyzer generally applicable to the competitive electricity markets.

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