Block Bidding Mechanism Incorporating Demand Side Participation

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***Abstract*—With respect to characteristics of block trading rules, integrating various implementation mechanisms of demand side bidding (DSB), block bidding mechanism is extended to demand side and theory framework of block bidding mechanism incorporating demand side participation is proposed. Based on electricity pool pattern and with block bidding rules, electricity sellers and buyers can perform electricity trading in bilateral block bidding electricity markets. Furthermore, this paper analyzes implementation scheme of bilateral block bidding in detail, including block classification method, bidding rules and market clearing algorithm etc. The framework is beneficial to effective demand side participation in electricity markets, strengthens the relation between electricity supply and demand, and enhances energy trades efficiency.**

***Index Terms*—Block bidding; demand side bidding; bilateral block bidding; demand response**

NOMENCLATURE

A. Parameters

i Index of seller
j Index of buyer
k Index of "price-capacity" staircase
l Index of block
N_G Number of sellers
N_D Number of buyers
L Number of blocks
K Number of "price-capacity" staircase
t_l Lasting time of block l
$\overline{q_{Gi}}$ Max technical output of seller i
$\underline{q_{Gi}}$ Min technical output of seller i
$\overline{q_{Dj}}$ Max consumption pattern of buyer j
$\underline{q_{Dj}}$ Min consumption pattern of buyer j
λ_l Lagrange multiplier corresponding to (5)
p_l^{MCP} Clearing price of block l
p_{Gik}^{bid} Bidding price of ith seller in kth staircase
q_{Gik}^{bid} Bidding capacity of ith seller in kth staircase
p_{Djk}^{bid} Bidding price of jth buyer in kth staircase
q_{Djk}^{bid} Bidding capacity of jth buyer in kth staircase

B. Functions

F Total objective function
F_l Objective function corresponding to block l

C. Variables

q_{Gik} Clearing capacity of ith seller in kth staircase
q_{Djk} Clearing capacity of jth buyer in kth staircase
q_{Gi} Clearing capacity of ith seller
q_{Dj} Clearing capacity of jth buyer

I. INTRODUCTION

THE worldwide deregulation and restructuring have led to many changes in the way of electricity trading. Active demand side participation [1] is playing more and more important roles in power systems. Treating supply side and demand side equally during market design process is a popular trend especially in integrated resource planning. In view of this background, it is of great theoretical and practical value to study reasonable market mechanism in which supply side and demand side can compete equally and efficiently.

As a unique commodity, electricity has its special meaning in value, which is brought forward by the authors of [2]. Because base-load power and peak-load power bring different effects on power system operation and electricity generation, the value of them is different. Therefore the power should be divided into several continuous blocks that are traded separately at respective prices. Block bidding [2]–[4] is a novel bidding theory in electricity markets, in which electricity can be sold and bought in different blocks. And accordingly block bidding mechanism reflects the rule "the same quality, the same price". Compared to hourly bidding mechanism, block bidding can lower market electricity purchasing fee effectively, obtain high market trades efficiency and reflect market equity.

Demand side bidding (DSB) is an important measure of demand response (DR) [5] in electricity markets. It enables demand side to actively participate in electricity market competition and offers customers the opportunity to obtain

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economic rewards by changing their electricity consumption pattern. Load serving entity, electricity retailer and large customer can enroll in DSB programs directly while small customers can participate in DSB programs indirectly by third-party aggregator.

So far, studies on block bidding mainly focus on power supply side (block bidding based unilateral electricity market), and its applications to demand side don't expand fully yet. With respect to characteristics of block trading rules, integrating various implementation mechanisms of demand side bidding [6], this paper aims to extend the block bidding mechanism to demand side. Theory framework of block bidding mechanism incorporating demand side participation, namely bilateral block bidding, is proposed, which is the new concept developed in the paper. Based on these block trading rules, power supplier, electricity retailers and customers of the demand side can involve in the wholesale market bidding, i.e., provide the demand bidding curve which is similar to the supply side bidding curve. Within this novel scheme, the buyer and seller need to schedule its bidding capacity among different block. A well-designed model of bilateral block bidding is proposed in this paper, and this work extends the paper [2]–[4]. Numerical results are finally used to prove the validity of the proposed model. The proposed framework provides a novel bidding scheme and enhances energy trades efficiency.

II. Framework of Bilateral Block Bidding

Unilateral competitive electricity trading mode didn't give customers the rights to choose their energy suppliers, and it didn't reflect the customer roles in the market. Therefore, in order to make electricity market more open and break the monopoly position of power grid companies, bilateral trading mode is proposed and put into practice. In light of market rules of block bidding based unilateral electricity market, block bidding based bilateral electricity market can be operated according to following basic rules:

A. Block Classification and Market Information Release

1) The block classification is pre-determined (e.g., the 24 hours duration is determined as a base-load block), while the clearing capacity and clearing price of each block need to be determined through bilateral block bidding process.

2) ISO classifies forecasted load profile into several continuous blocks, and method of block classification should be predetermined according to system conditions and considering opinion of power seller and power buyer. In bilateral block bidding markets, because clearing capacity of each electricity block are determined in bilateral trading, electricity can be approximately classified into several blocks to reflect difference between blocks, e.g. 5 blocks including 24h block, 16h block, 8h block, 4h block, 2h block.

3) In each trading day, ISO releases information of every block to all sellers and buyers, including block numbers, forecasted capacity, start & end time and number of submitted "price-capacity" of each block.

B. Bidding Rules of Market Participants

1) Each seller/buyer should submit their next-day bidding information of every block to ISO in day-ahead time.

2) According to block sequence of blocks, each seller/buyer should submit one bidding curve within the block in which the generation/consumption pattern is feasible. If any block is infeasible for seller/buyer, it doesn't need to submit any bidding curve.

3) Bidding curve should be staircase form, including bidding capacity and bidding price, i.e., "price-capacity".

4) Bidding capacity of seller should meet its max and min technical output constraints. Within each block, bidding price should increase as bidding capacity increases. And for different block, bidding price should increase as block capacity increases.

5) Bidding capacity of buyer should meet its max and min consumption pattern constraints. Within each block, bidding price should decrease as bidding capacity increases. And for different block, bidding price should increase as block capacity increases.

C. Market Clearing Rules

1) From the base-load block to the last block, ISO clears each block according to each seller and buyer bid. ISO arrange the clearing bidding capacity of each seller/buyer from their min technical output/consumption pattern constraints to their max technical output/consumption pattern constraints.

2) For each block, ISO will assembly all price-capacity curves from each seller/buyer to the bidding curve of supply side/demand side. Afterwards, ISO clears the block based on the rule of social welfare maximization (see next subsection) and all clearing capacity will be settled according to the uniform clearing price.

III. Market Clearing Model

In order to simplify the analysis, this paper does not consider the network constraints. Market clearing can be summed up to the optimization problem of social welfare maximization

Objective function formulation:

$$\text{Maximize } F = \sum_{l=1}^{L} t_l \left(\sum_{j=1}^{N_D} \sum_{k=1}^{K} p_{Djkl}^{bid} q_{Djkl} - \sum_{i=1}^{N_G} \sum_{k=1}^{K} p_{Gikl}^{bid} q_{Gikl} \right) \quad (1)$$

As the ISO clearing process of all blocks proceeds from the base-load block to the last block, the objective function above can be decoupled into separate clearing process within each block. For each block $l=1,2,\cdots,L$, the objective function can be represented as (omit the subscript l later):

Equivalent problem:

$$\text{Maximize } F_l = \sum_{j=1}^{N_D} \sum_{k=1}^{K} p_{Djk}^{bid} q_{Djk} - \sum_{i=1}^{N_G} \sum_{k=1}^{K} p_{Gik}^{bid} q_{Gik} \quad (2)$$

Subject to the following constraints:

$$\sum_{k=1}^{K} q_{Gik} = q_{Gi} \quad (i = 1,2,\cdots,N_G) \quad (3)$$

$$\sum_{k=1}^{K} q_{Djk} = q_{Dj} \quad (j = 1,2,\cdots,N_D) \quad (4)$$

$$\sum_{i=1}^{N_G} q_{Gi} - \sum_{j=1}^{N_D} q_{Dj} = 0 \quad (5)$$

$$0 \le q_{Gik} \le q_{Gik}^{bid} \quad (i = 1,2,\cdots,N_G; k = 1,2,\cdots,K) \quad (6)$$

$$0 \le q_{Djk} \le q_{Djk}^{bid} \quad (j = 1,2,\cdots,N_D; k = 1,2,\cdots,K) \quad (7)$$

$$\underline{q_{Gi}} \le q_{Gi} \le \overline{q_{Gi}} \quad (i = 1,2,\cdots,N_G) \quad (8)$$

$$\underline{q_{Dj}} \le q_{Dj} \le \overline{q_{Dj}} \quad (j = 1,2,\cdots,N_D) \quad (9)$$

The problem above is a linear programming model, and the decision variables are q_{Gik} (N_G*K) and q_{Djk} (N_D*K). Eq. (2) is the objective function; Eq. (3) and Eq. (4) are bidding power equality constraints for seller/buyer; Eq. (5) is the power balance constraint; Eq. (6) and Eq. (7) are block capacity constraints for seller/buyer; Eq. (8) is min/max technical output constraints for seller; Eq. (9) is min/max consumption pattern constraints for buyer.

In this paper, the MATLAB linear programming function is adopted to solve the above model. According to the Kuhn-Tucker theorem, the market clearing prices of each block can be represented as:

$$p_l^{MCP} = \lambda_l \quad (l = 1,2,\cdots,L) \quad (10)$$

Where λ_i is the Lagrange multiplier corresponding to (5).

The analysis above is clearing process of a single block. When concerning about multiple blocks in practice, the clearing process can proceed from the longest duration block to the shortest duration block. Trading process of bilateral block bidding market is shown in Fig. 1:

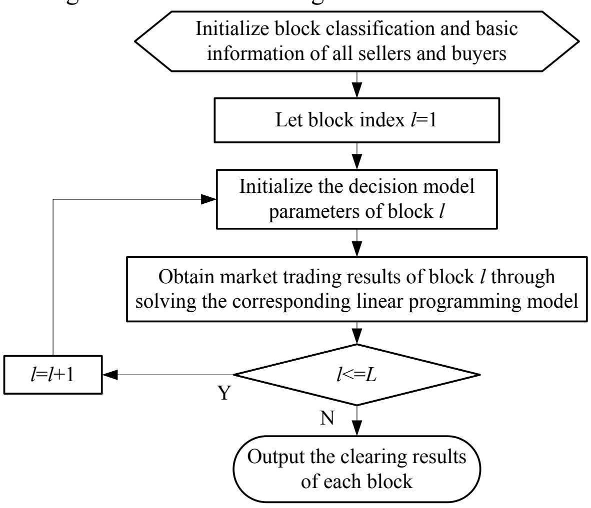

Fig. 1. Trading process of bilateral block bidding market

IV. CASE STUDY

In this section, a bilateral block bidding market in which 5 sellers and 5 buyers participate in bidding is taken as an example for analysis to illustrate the performance of the proposed approach. The clearing price and clearing capacity of each block can be obtained through the model above.

As is illustrated in [2], block bidding requires the power to be divided into several blocks according to its lasting time. How to divide the load efficiently is an interesting work, and it needs further study. In this paper, power is divided into 5 blocks: 24-hour block, 16-hour block, 8-hour block, 4-hour block and 2-hour block. Fig. 2 and Table I illustrates the divided blocks. Table II to Table V illustrate the lower and upper bounds of bidding capacity for all sellers and buyers respectively.

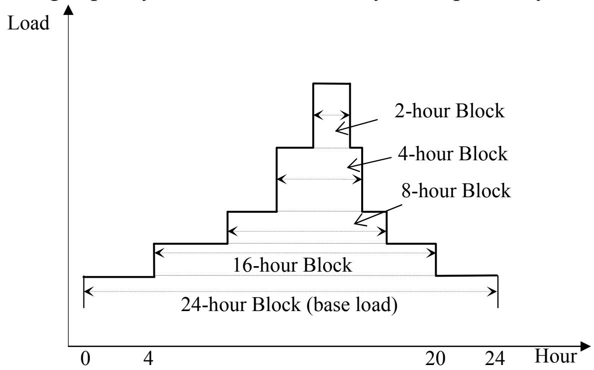

Fig. 2. The divide of power block

TABLE I INFORMATION OF EACH BLOCK

Block index	Start time (h)	Lasting time (h)
1	00:00-24:00	24
2	04:00-20:00	16
3	10:00-18:00	8
4	13:00-17:00	4
5	15:00-17:00	2

TABLE II LOWER BOUNDS OF BIDDING CAPACITY FOR SELLERS (MW)

Block index	Seller 1	Seller 2	Seller 3	Seller 4
1	400	480	450	470
2	300	220	350	360
3	200	110	260	240
4	100	70	130	150
5	50	30	65	70

TABLE III UPPER BOUNDS OF BIDDING CAPACITY FOR SELLERS (MW)

Block index	Seller 1	Seller 2	Seller 3	Seller 4
1	900	840	850	780
2	800	740	750	730
3	700	680	650	640
4	600	540	550	580
5	480	440	470	450

TABLE IV LOWER BOUNDS OF BIDDING CAPACITY FOR BUYERS (MW)

Block index	Buyer 1	Buyer 2	Buyer 3	Buyer 4
1	450	480	440	420
2	330	230	350	350
3	210	140	280	230
4	100	90	140	150
5	50	30	65	70

TABLE V UPPER BOUNDS OF BIDDING CAPACITY FOR BUYERS (MW)

Block index	Buyer 1	Buyer 2	Buyer 3	Buyer 4
1	850	830	870	760
2	760	720	780	710
3	680	690	670	630
4	590	540	550	580
5	470	420	450	440

Due to space limitations, this paper only listed the bidding data of all sellers and buyers within the 24h and 16h block in Table VI and Table VII respectively.

TABLE VI BIDDING DATA FOR ALL SELLERS AND BUYERS WITHIN THE 24H BLOCK

	Bidding capacity (MW)			Bidding Price ($/MWh)		
k	1	2	3	1	2	3
Seller 1	400	400	300	10	12	14
Seller2	400	300	300	11	13	16
Seller 3	300	300	200	12	13	15
Seller 4	300	200	200	13	14	15
Seller 5	200	200	300	14	15	16
Buyer 1	400	300	300	17	15	13
Buyer 2	300	300	500	20	18	16
Buyer 3	200	300	200	19	17	15
Buyer 4	200	300	200	21	18	15
Buyer 5	200	100	300	22	19	17

TABLE VII BIDDING DATA FOR ALL SELLERS AND BUYERS WITHIN THE 16H BLOCK

	Bidding capacity (MW)			Bidding Price ($/MWh)		
k	1	2	3	1	2	3
Seller 1	300	300	300	11	13	15
Seller2	300	200	200	12	14	17
Seller 3	300	300	200	13	14	16
Seller 4	200	200	200	14	15	16
Seller 5	100	200	300	15	16	17
Buyer 1	300	200	300	18	16	14
Buyer 2	200	300	300	21	19	17
Buyer 3	200	300	100	20	18	16
Buyer 4	200	300	200	22	19	16
Buyer 5	200	200	300	23	20	18

Iteration times of clearing solution process within each block are all 7 times when using MATLAB as the solution tool. Table VIII lists market clearing prices and optimal social welfares within each block. In addition, the total optimal social welfares can be summed up from that value of all blocks. It can be observed from this table that market clearing prices increase as block index increase (i.e., block lasting time decreases), which reflects the energy value difference between different blocks.

TABLE VIII MARKET CLEARING PRICES AND OPTIMAL SOCIAL WELFARES

Block index	Lasting time (h)	Clearing price ($/MWh)	Optimal social welfare ($)
1	24	15	415920
2	16	16	246720
3	8	17	93600
4	4	19	40280
5	2	20	18600
Total	–	–	815120

Due to space limitations, this paper only listed the clearing capacity of all sellers and buyers within the 24h and 16h block in Table IX and Table X respectively.

TABLE IX CLEARING CAPACITY FOR ALL SELLERS AND BUYERS WITHIN THE 24H BLOCK

	Clearing capacity (MW)		
k	1	2	3
Seller 1	400	400	100
Seller2	400	300	0
Seller 3	300	300	83.38
Seller 4	300	200	104.33
Seller 5	200	190.51	0
Buyer 1	400	204.84	0
Buyer 2	300	300	230
Buyer 3	200	300	129
Buyer 4	200	300	114.28
Buyer 5	200	100	300

TABLE X CLEARING CAPACITY FOR ALL SELLERS AND BUYERS WITHIN THE 16H BLOCK

	Clearing capacity (MW)		
k	1	2	3
Seller 1	300	300	200
Seller2	300	200	0
Seller 3	300	300	106.25
Seller 4	200	200	167.26
Seller 5	100	179.24	0
Buyer 1	300	69.72	0
Buyer 2	200	300	220
Buyer 3	200	300	27.47
Buyer 4	200	300	35.56
Buyer 5	200	200	300

V. CONCLUSIONS

This paper proposes framework of block bidding mechanism incorporating demand side participation, integrating block trading rules and various implementation mechanisms of DSB. The framework is beneficial to effective demand side participation in electricity markets, exerts the advantage of block bidding theory, and provides a useful attempt in the selection of bilateral market scheme**.** In a practical point of view, if more detailed block classification method and bidding rules can be established, the framework could be readily applied to large-scale power systems, which is also an interesting area for further study.

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