Integrated Demand and Supply Side Pricing Optimization Schemes for Electricity Market

Zixu Liu and Xiao-Jun Zeng

Abstract It is widely agreed that an increased communication among different groups (generators, retailers and customers) in electricity market would produce benefit not only for a single group but also for the market as a whole. This paper investigates and develops integrated pricing optimization schemes and coordination mechanisms for the electricity market which considers the supply and demand within one framework. In this framework, generators, retailers and customers aim to maximize their own benefits. Simulation results confirm that every group achieves their objectives in the designed market. In order to ensure the fair distribution of cost and benefit, and maximize the social welfare in the market, the Independent System Operator coordinates and balances these conflict goals using proposed mechanisms.

Keywords Demand response · Elasticity matrix · Linear programming · Quadratic programming

1 Introduction

The electricity market can be divided into two parts: the wholesale electricity market and the retail electricity market. A wholesale electricity market exists when competing generators offer their electricity output to retailers at the wholesale prices. The main problems in wholesale electricity market are how to minimize the generators' production cost and price the electricity for retailers. A retail electricity market exists when the retailers sell electricity to customers in retail prices. Besides, the main issue in retail electricity market is the way of retailer's re-pricing.

Every group in the electricity market has different objectives. For example, retailers and generators aim to maximize their own profit. In order to achieve that goal,

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generators and retailers would reduce their cost and price the electricity higher for retailers and customers respectively. In contrast, customers would like their electricity bills as little as possible. Furthermore, unlike other products electricity is hard to keep in stock, ration or have customers queue for. It has to be always available for demands. Therefore, a controlling agency, the Independent System Operator (ISO) [1], is needed to coordinate the dispatch of generation units to meet the expected demands of system across the transmission grid [2]. But in real-time pricing, customers have the incentive to reduce their electricity usage at the peak period or to shift their usage to off-peak period, which makes the generation scheme hard to make in wholesale market. It is hard or impossible for all to achieve their objectives at the same time. Therefore, a market-coordination mechanism which can effectively balance the demand and supply by taking into account customers' reaction is needed for a market. Besides, the performance of a market is measured by the social welfare which has been shown in [3]. To achieve such a social welfare goal, ISO thus has to perform an optimization coordination scheme to select the optimal production scheme and calculate the market-clearing price. As mentioned above, a common electricity market is supposed to increase social welfare by ensuring the security of supply, stimulating competition, and negotiating through non-discriminatory third-party (ISO).

Most of the existing researches deal with the wholesale market and retail market separately [4–7]. For example, [5] proposes a Stackelberg game approach to maximize the profit for the electricity retailers (utility company) and minimize the payment bills of its customers. According to the proposed smart energy pricing scheme, the retailer determines the retail price to optimally adjust the real-time pricing with the aim of maximizing its profit. [7] considers a demand response problem in a network of multiple retailers and consumers where every entity desires to maximize its own profit. The authors propose a Stackelberg game between retailers and end-users to maximize the revenue of each retailer and the payoff of each user. They derive analytical results for the Stackelberg equilibrium of the game and prove that a unique equilibrium exists. However, in all above researches, they only focus on a part of the entire electricity market: either the wholesale market or the retail market. [4, 5, 7] do not consider that the change of demands will influence the generation cost and the market clearing price in the wholesale market, and thus undoubtedly changes the retailers' pricing strategy. [6] only considers the wholesale market but totally neglects the effects of demand side, e.g., the influence of customers' demand shifting.

In order to overcome the aforementioned weakness, some of the researches introduce the demand response in retail market to the wholesale market, such as [8–11]. Through using demand response program to predict customers' consumption behaviors, retailers can decide how much power they should buy or ISO can schedule the production scheme for generators. For example, [9] factors the elasticity matrix of demand in electricity prices for customers. This matrix reflects the customer's reaction to the electricity prices. With this model, the integrated electricity market can price the electricity in the retail market and improve the effectiveness for the wholesale market to avoid the waste of surplus electricity. In [10], the authors quantify the effects of demand response on the electricity markets. It proves that with the participation of customers, their demand shifting can significantly reduce the operating cost in generation side. Although [9, 11] introduce the advantage of considering demand response when scheduling generation scheme and pricing for electricity in the market, the customers' elasticity matrix and pricing model are weak. In [10], the generators and retailers are required to submit their generation information, which obviously conducts the gaming behaviour for some participants. In order to increase the profit, some participants have the intentions to report wrong information to ISO. Therefore, this paper mainly concentrates on solving the issues existing in current researches.

From the information mentioned above, the motivations of this paper are two-folds. The first motivation is to integrate the demand and supply sides into one framework. Within this framework, this paper investigates and develops the integrated pricing optimization schemes for generators and retailers. The second motivation is to investigate and develop the coordination mechanism for electricity market. Because every participant in the market wants to maximize his own benefit, a conflict situation is obviously induced. If the retailers set a flat higher price and get their maximized profit in all periods, there is no time period customers can shift their demands to, thus the benefit of customers can't be ensured. So how to coordinate and balance all groups' conflict goals is the second motivation of this paper. Based on these motivations, the main contribution of this paper can be summarized as follows: this paper develops an integrated framework and a method of pricing optimization which integrates and enhances the existing demand modelling, the retailers' pricing optimization and the generators' cost minimization methods. Based on this integrated framework and method, a computing simulation tool for ISO is developed to support the ISO to find the best acceptable and negotiable scheme which coordinates and balances conflict goals among the generators, retailers and customers. This ensures the fair distribution of cost and benefit among all groups in the market.

The rest of paper is organized as follows. The proposed simulation tool for the integrated market and related algorithms for ISO are presented in Sect. 2, and the detailed balance mechanism designed for ISO is given in Sect. 3. Section 4 displays and discusses the numerical results, while the future work is described in Sect. 5.

2 Problem Formulation and Simulation Tool

As in [8, 12], this paper considers a smart power system with several retailers and lots of customers as part of the general electricity market which is shown in Fig. 1. The retailer buys power from generators and sells it to its customers. The energy management controller (EMC) in each customer's home interacts with the retailer through an underlying two-way communication network (e.g., the smart metering infrastructure) [13]. With EMC, the retailer can record the usage information of each

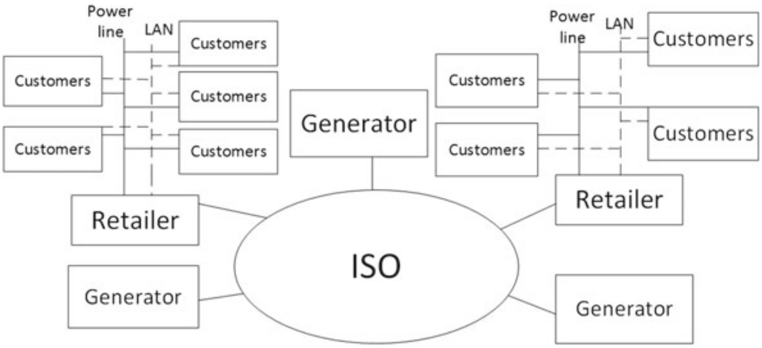

Fig. 1 The structure of electricity market

customer. In the proposed model, an Independent Operation System (ISO) exists in the wholesale market as a market coordinator. ISO schedules production scheme and sets the Market Clearing Price (MCP) for retail market while minimizing the generation cost.

As shown in Fig. 1, there are four parts in the market: generators (power provider) which produce the required electricity from the retail market; ISO which schedules the generation scheme and determines the MCP which acts the coordinator in the market; retailers (power provider) which buy the electricity from the wholesale market based on MCP and sell it to its customers after re-pricing the electricity; customers which decide quantity of electricity they brought from their retailer after receiving price. The whole process in proposed mechanism runs as follows, which is also shown in Fig. 2. Firstly, retailers estimate customers' hourly aggregated demand of next day and sent it to ISO, this estimated data is called the vector of expect demand. Then each generator reports the price and the quantity of production as its bid to ISO. According to these bidding information, ISO schedules the optimal generation scheme and calculate the MCP. According to the generation scheme, generators can know the expected output for each hour in the next day. The decision of which generator should be on or off for the next day in production scheme is known as unit commitment. The specific amount of electricity those committed generators should produce is known as economic dispatch [2]. After receiving MCP, each retailer prices the electricity for each hour in next day to maximize its own profit according to the predicted customers' consumption behaviour. Customers react with the price vector of next day which can change their demand. The customers' new expected demand is estimated by retailer and sent to ISO again. After that, ISO compares the new expect demand with the supply (old expected demand). If the supply and demand are not balanced, then start with a new loop. Otherwise the process will be ended if the difference between the old expected and new expected demand is converged to near zero.

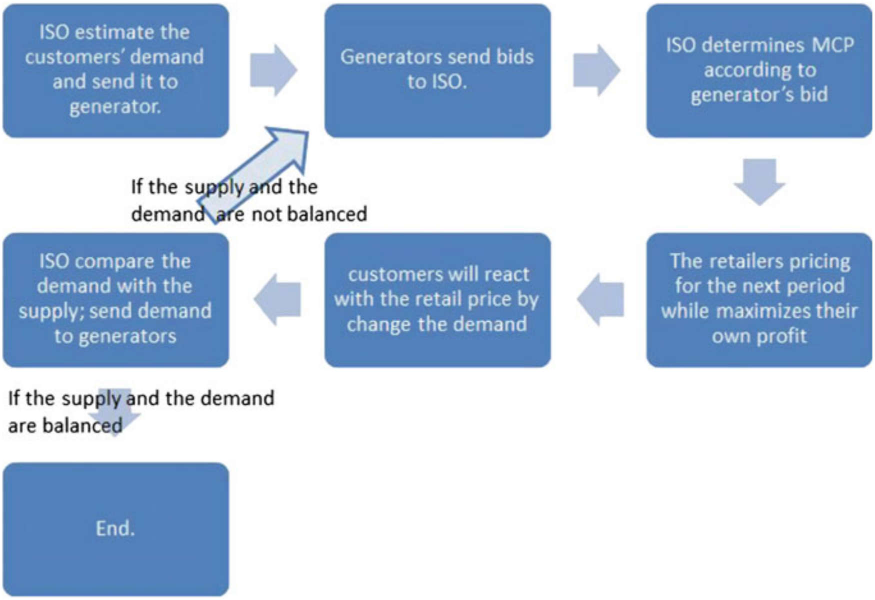

Fig. 2 Working process of proposed mechanism

2.1 *Generator's Offer*

In generation part, this paper chooses complex bid as the generators' bidding strategy. A complex bid may include separate price for ramps, start-up cost, shut-down costs, no-load cost and energy [3]. Generators submit complex bids that embody not only their operational cost but also their operational constraints. The operating cost includes the running cost and the start-up cost. The up and down ramping rates of the generators as well as the minimum up and down time constrains are not considered in this paper. This part is too complicated that will be added in the future research work. Equation 1 is the cost function for each generator. Step function is used to describe the cost curve ($C^{i,h}$). The step function can approximate other bid formats, such as piecewise linear bid curve which is required by the California Power Exchange [14, 15]. In mathematics, a function on the real numbers is called a step function if it can be written as a finite linear combination of indicator of intervals. This interval is called a segment in the curve.

$$OC_i^h = \sum_{h=1}^{H}(C^{i,h}(E_i^h - E_{min}^i)) + u^{i,h}S^{i,h}), \tag{1}$$

$$C^{i,h} = \sum_{b=1}^{b} MC_{i,b} \times PL_{i,b}, \tag{2}$$

where

- i: The i-th generators;
- $S^{i,h}$: Start-up cost of generator i, a minimum level generation E^i_{min} will be produced;
- OC^h_i: Operation cost of generator i during period h. this paper use 24 h as pricing window;
- $u^{i,h}$: Status of generator i during period h (0 off, 1 on). For $h = 1$, $u^{i,0} = 0$.
- $C^{i,h}(E^h_i - E^i_{min})$ Production cost above E^i_{min} for generator i, E^h_i is the required production during hour h;
- $MC_{i,b}$ Marginal production cost of generator i on segment b of its step function cost curve;
- $PL_{i,b}$: Output of generator i on segment b of its step function cost curve;

$$\min OC^h(D_h) = \sum_i OC^h_i(E^h_i) \tag{3}$$

$$= \sum_i (\sum_{b=1}^{b} C^{i,h}(E^h_i - E^i_{min}) + u^{i,h}S^{i,h})$$

$$\text{s.t.} \quad \sum_i E^h_i \geq D_h$$

Through solving problem in Eq. 3, ISO can get the production scheme of next day with the minimum cost. According to this schedule, ISO notifies every generator which level of production is needed in hour h.

2.2 Independent System Operator (ISO)

As the market administer, ISO has the responsibility to keep the electricity market stable. When all factors keep the same, ISO should achieve the following objects:

1. Customers' bill no more than yesterday,
2. Keep all generators' profit in certain level,
3. Retailers maximize its profit but no more than restriction set by ISO.

So that means ISO administers and manages generators and retailers in the market. In return for this authority, ISO ensures all generators' and each retailer's profit in pre-negotiated level.

In order to keep all generators' profit in a certain level, ISO calculates the MCP of the next day after scheduling generation scheme. Usually MCP is the first losing bid of generator. But in this paper, ISO slightly increases the MCP to ensure all generator's profit in next period H until no less than pre-negotiated level (p_g). The object of ISO is to increase MCP at each hour as small as possible. Therefore, this problem can be formulated as following optimization problem.

$$\min \sum_h MCP_h \ \ for\ h = 1, \ldots, 24. \tag{4}$$

$$\text{s.t.} \sum_h (MCP_h \times E_i^h - C^{i,h}) \geq p_g \ \ for\ i = 1, \ldots, n;$$

$$MCP_h \geq mcp_h \ \ for\ h = 1, \ldots, 24;$$

where *mcp* is original market clearing price obtained by production scheme; *MCP*, *P* and *mcp* are vectors; both *E* and *C* are matrix. This linear programming problem in Eq. 4 can be solved by Matlab software.

2.3 Retail Market

Throughout the paper, we assume the price and demand information in retail market of last N days is available. Using Ma's method in [4], we get the customers' estimated reaction function for each hour from the demand modelling by learning the historical data. The form of estimated reaction function for each hour h can be represented as:

$$RF_h(p_1, p_2, \ldots, p_H) = \alpha_h + \beta_{h,1} p_1 + \cdots + \beta_{h,H} p_H. \tag{5}$$

The $\beta_{h,c}$ in the function can be treated as the cross-price elasticity of demand of electricity which can be formulated as:

$$\beta_{h,c} = \frac{\% \triangle d_h}{\% \triangle p_c} = \frac{\triangle d_h}{\triangle p_c} \times \frac{d_h}{p_c}. \tag{6}$$

The $\beta_{h,c}$ measures the responsiveness of the customers' demand for the electricity at hour $h \in H$ to change in price of electricity at some other hour $c \in H$, which is always greater than 0. When h equals to c, $beta_{h,h}$ is defined as self-elasticity, which is always less than 0. Ma uses the adaptive least square method to update parameters in Eq. 5 for each hour h when any new data are available [4].

The next step is to solve the problem of how to set the prices of electricity in next day to achieve the maximum profit for retailer at certain constrains. In this part, the pricing model for profit maximization will be discussed.

For each hour $h \in H$, we define the minimal and maximal price that the retailer can offer to its customers.

$$p_h^{min} \leq p_h \leq p_h^{max} \tag{7}$$

where p_h^{min} and p_h^{max} are usually set based on several factors, such as the cost of electricity (wholesale price), customers' average income and affordability, and the constraints from government policy. For instance, usually in order to avoid a loss, the retail price of electricity should be higher than the wholesale price of it. On the other hand, the upper bound of the retail price of electricity is often from competitors. But this paper considers retailer and its customers as a monopoly game which is also shown in Fig. 1. There is no competition between retailers, which means customers do not have options to choose the retailer. And the electricity is a life necessity, which means no matter how much the price of electricity changes, the demand of electricity does not change too much. Therefore there must exist a constraint on the prices which are possible from government policy or customers' acceptability.

Similar to the constraints Eq. 7, a constraint on the total revenue should exist due to customers' acceptability. Thus, we have the constraint.

$$\sum_{h \in H} p_h \times RF_h(p_1, p_2, \ldots, p_H) \leq C_N \tag{8}$$

where C_N is customers' bill of day N. With constrains discussed before, the objective function for each retailer j can be expressed as follows, Where RE^j_h is the energy the retailer j brought from wholesale market during hour h. C^j_N is the bill of all retailer j's customers of day N. PRR_j is the total profit of retailer j at period H.

$$\begin{aligned} \max PRR_j = & \sum_{h \in H} (p^j_h \times RF_h(p^j_1, p^j_2, \ldots, p^j_H) - MCP_h \times RE^j_h) \\ \text{s.t.} \quad & \sum_{h \in H} p^j_h \times RF_h(p^j_1, p^j_2, \ldots, p^j_H) \leq C^j_N \\ & p^{min}_h \leq p_h \leq p^{max}_h, \forall h \in H \end{aligned} \tag{9}$$

Retailer j can price the electricity of next day for customers and maximize the profit by solving the optimization problem in Eq. 9. Under the constraint in Eq. 8, ISO ensures customers' bill no more than yesterday. Besides, ISO also need to ensure retailer's profit in a certain level. Sometimes the result of problem Eq. 9 can't satisfy Eq. 10, for example when the production cost changes. Then retailer should adjust the sale price to ensure its profit satisfy Eq. (10).

$$PRJ^N_j - \delta \leq PRJ^{N+1}_j \leq PRJ^N_j + \delta \tag{10}$$

For adjust process, retailer j should change the Eq. 10 to Eq. 11 first to ensure its profit.

$$p^j_h \times RF_h(p^j_1, p^j_2, \ldots, p^j_H) \leq C^j_N + \Delta \tag{11}$$

$$\Delta = \Delta_0 + (k-1)\varepsilon \tag{12}$$

where k is the number of iterations times. Then solve the problem Eq. 9 again. Until satisfy the Eq. 10. This can be formulated as Eq. 13:

$$\begin{aligned} & \min \quad \Delta \\ & \text{s.t.} \; PRJ^N_j - \delta \leq J(\overrightarrow{p^j}) \leq PRJ^N_j + \delta \end{aligned} \tag{13}$$

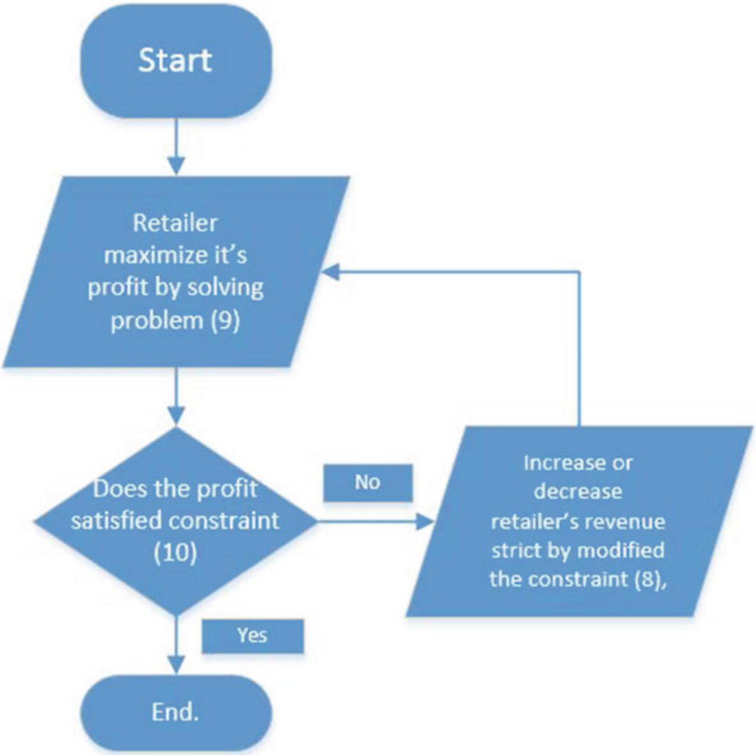

Fig. 3 The working process of retailer's pricing model

In order to easily understand the pricing model in retailer market, the whole working process is shown below in Fig. 3. The problem Eq. 9 is a quadratic programming problem and can be solved with the SCIP solver from OPTI TOOLBOX.

3 Balance Mechanism

In last section, we introduced the proposed simulation tool for electricity market and related algorithms. However, this simulation tool relies on a stable generation cost. But the price of oil or fuel is always fluctuating. The generation cost would be certainly affected by this fluctuation. In proposed model, the profits of the retailers and generators are controlled at the certain range. For customers' part, the bill of all retailer j's customers in day $N + 1$ is formulated below.

$$C^j_{N+1} = \sum_{h \in H} p^j_h \times RF_h(p^j_1, p^j_2, \dots, p^j_H) \tag{14}$$

With the same parameter, ISO always wants the bill of *j*'s customers no more than yesterday. So this constraint sets the limitation to retailer *j*'s profit. That is:

$$C^{j}_{N+1} \leq C^{j}_{N} \tag{15}$$

But Eq. 15 can not be satisfied when the production cost increases in wholesale market, because the increase of generation cost and the change of generators' profit are transferred to customers' bill. As non-discriminatory third-party and administrator in the market, ISO desires all groups take the responsibility for the increasing cost when the generation cost increases. Therefore, this paper designs a balance mechanism for ISO.

The balance mechanism runs based on the result of simulation tool talked in Sect. 2. Assume the simulation tool stops after M-th loop. We use C_b to describe the change of all customers bill after generation cost changes. D^{j}_{b} is used to describe estimated demand of retailer *j*' customers at loop $M-1$, which is also the quantity of electricity retailers want to buy from ISO. D_b equals to the sum of all retailers' D^{j}_{b}. D^{j}_{r} is the estimated demand of retailer *j*'s customers which reacting with *j*'s sell price at loop M. Then here we can get the quantity of final sales electricity for retailer *j*: S_j, where S_j equals to the sum of S^{h}_{j} in 24 h. S^{h}_{j} is the final sales electricity of retailer *j* in hour *h*. Similarly we define D^{j-h}_{b} and D^{j-h}_{r}. Equation 16 describes their relation. Due to the reasons of all values used in this section are obtained from the running results of simulation tool in Sect. 2. Therefore D^{j-h}_{b} and D^{j-h}_{r} are closed enough. So this small quantity of electricity shortage or surplus in each hour for each retailer is not a big problem.

$$S_j = \begin{cases} D^{j}_{b} \ \ if \ D^{j}_{b} \leq D^{j}_{r} \\ D^{j}_{r} \ \ if \ D^{j}_{r} \leq D^{j}_{b} \end{cases} \tag{16}$$

Every group should afford C_b proportionally when the generation cost increases. That is an advanced property of proposed market model. In most electricity market, customers play a much more limited role than generators and retailers. They just accept the price passively without any ensured welfare. So in this paper, customers will positively participate in wholesale market with the help of this policy.

Here use a, b and c to represent the proportions generators, retailers and customers should afford respectively, where the sum of a, b and c is 1 (the value of a, b and c should be negotiated by ISO, retailer and generators). Use MCP^{f}_{h} and Pr^{j-f}_{h} to describe the balanced MCP in wholesale market and retailer *j*'s balanced sales price in hour h respectively.

$$MCP^{f}_{h} = MCP_{h} - \frac{C_b \times a}{D_b}, \ \ \forall h \in H \tag{17}$$

$$Pr_h^{j-f} = Pr_h^j - \frac{C_b \times b \times D_b^j}{D_b \times S_j} - \frac{\frac{C_b \times a}{D_b} \times D_b^j}{S_j}, \quad \forall h \in H \tag{18}$$

where MCP_h and Pr_h^j are the market clearing price and sales price of retailer j obtained by Sect. 2 in loop M. After calculates the MCP_h^f and Pr_h^{j-f}, ISO finished the balance mechanism. Using this result, customers don't need to passively take all the responsibility of increased production cost.

4 Numerical Results

This section shows the simulation results and the analysis of the proposed simulation tool in Sect. 2. Firstly, Sect. 4.1 displays the parameters which are needed in the simulation. All the data used here are obtained from the PJM. Secondly, Sect. 4.2 analyses the simulation results (Fig. 4).

4.1 Parameter Setting

Based on the model shown in Figs. 1 and 2, the simulation assumes there are ten generators and two retailers in the market. Two retailers have their own customers

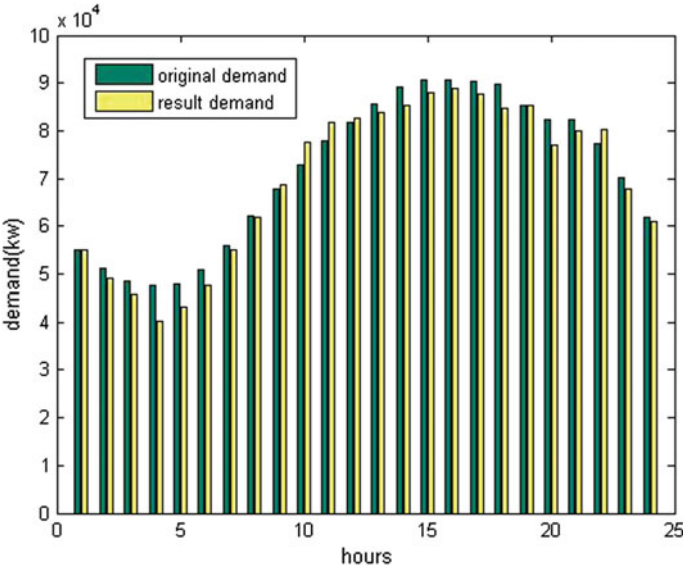

Fig. 4 Comparison between test demand and result demand

Table 1 Retailer's parameters

	Retailer 1	Retailer 2
Revenue restriction	34347000	34347000
Maximum profit	3022200	3622200
Maximum sell price	49.6650	68.3980

Table 2 Generators' production information

G	Segment output (kW)				Marginal cost (cents/kW)			
1	1000	1000	1000	1000	19.71	21.13	26.27	35.86
2	1500	1500	1000	1000	22.95	24.74	30.65	41.24
3	2200	1800	2000	1500	21.33	22.38	26.986	36.10
4	2600	2000	1400	2000	21.19	22.22	26.78	35.53
5	2600	1400	4000	1400	23.22	24.10	29.15	38.82
6	3200	2800	4000	2000	24.03	25.47	31.27	41.99
7	4500	1500	4000	4000	26.46	28.21	34.93	48.72
8	5000	3000	4000	3000	25.38	26.92	32.85	44.10
9	5500	2500	4000	5000	23.22	24.37	29.74	40.57
10	6000	4000	6000	4000	25.51	26.80	33.04	44.78

which means no competition between them. The parameters of maximum sales price, strict revenue and the profit are set different for these two retailers. In Eq. 10, the d is set as 5000 cents, so their profit will be no more or less than PRJ_j^{d-1} about 50000 cents. The difference between two retailers set here represent the controllable ability of ISO. Every group in the market is monitored by ISO. The difference between two retailers is shown in Table 1. For generation part, this paper sets ten different scales of generators. The minimum total profit of ten generators is 1.1433e+07 cents. The production information of ten generators is shown in Table 2.

The process in Fig. 2 shows the difference between new estimated demand from the result and estimated demand from the precious loop (supply in result) is the main factor to determine the program whether running or not. In this section, this difference is called *demand-difference*. Figure 5 shows the value of the *demand-difference* of two retailers in 24 h. The figure shows that the *demand-difference* in most hours converges to 100 kW. Even for the biggest difference in hour 5, 1782.9 kw is a really small number compared with the demand of retailer 1's customers in that hour, which is also proved in Fig. 6. Figure 7 compares the electricity of retailer 1 brought from ISO and estimated customers' reacted demand. The demand- difference is really a small number compared with the brought electricity in each hour, which improves the requirement of UC is achieved in proposed model.

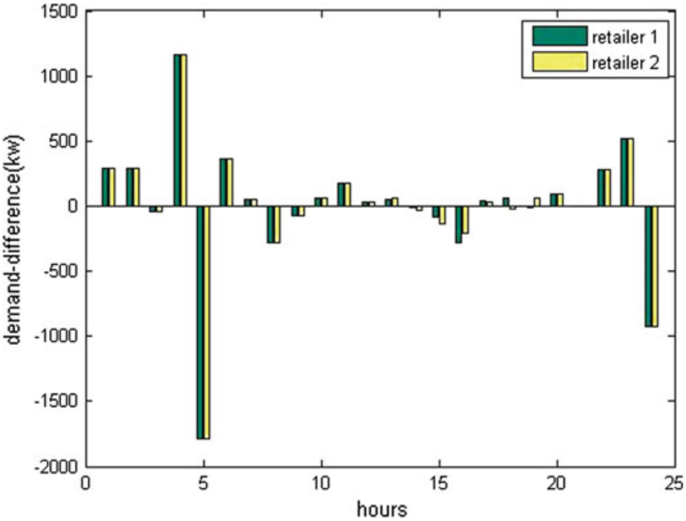

Fig. 5 Demand-difference of two retailers

Finally, the market clearing price vector and retailer's price in final result are shown in Fig. 7. The figure shows that retailers increase the price compared with MCP in hours 14, 16, 17, 18, 20 and 21, all of these hours are in the peak-times. That proves the pricing optimization model of this paper is reasonable. Because this pricing model encourages customers shift their consuming electricity from the peak hours to off-peaks hours.

4.2 Simulation Results

This part shows the running results of proposed mechanism based on parameters shown in Sect. 4.1. Requirements of minimum generation cost and total profit of generators can be easily reached in wholesale part, therefore part B mainly analyses the results of retail market. The test demand in the simulation is shown in Table 3. Every retailer has its own demand. After 9 times of loop, the result of retailer 1's and 2's profit are 2.9889e+06 cents and 3.6032e+06 cents respectively, the corresponding revenues are 3.06460e+07 cents and 3.1258e+07 cents. All of these values are controlled in the pre-set range which shown in Table 1. Figure 4 compares the original demand (Table 3) and the result demand of customers.

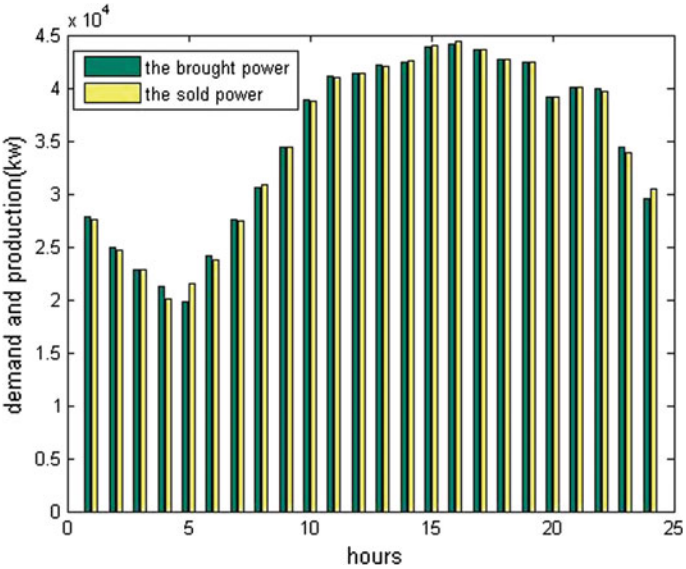

Fig. 6 Demand-difference of retailer 1

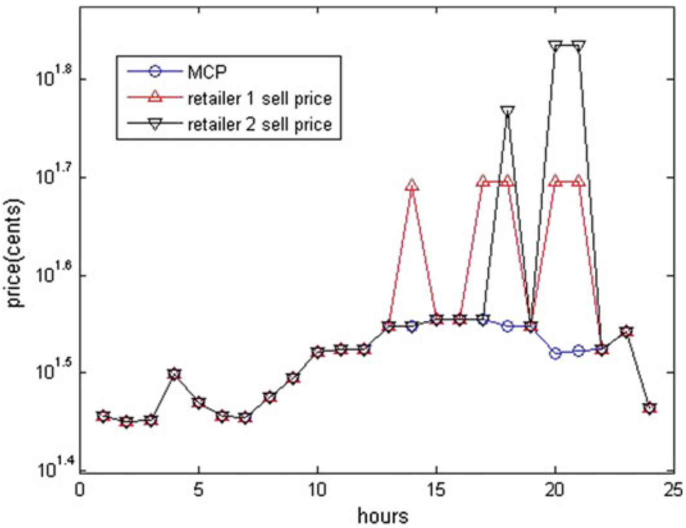

Fig. 7 MCP (*red*) and retailers' sales price (1 *blue*, 2 *green*)

Table 3 Comparison between test demand and result demand

Hour	1	2	3	4	5	6	7	8
R1	27094	25339	23952	23455	23676	25222	27860	31037
R2	27891	25931	24623	24085	24250	25753	28142	31205
Sum	54985	51270	48575	47540	47926	50975	56002	62242
Hour	9	10	11	12	13	14	15	16
R1	33684	36063	38362	40298	42127	43604	44497	44395
R2	34055	36878	39570	41531	43612	45470	46095	46121
Sum	67739	72941	77932	81829	85739	89074	90592	90516
Hour	17	18	19	20	21	22	23	24
R1	44278	43967	42292	41029	41201	38338	34890	30838
R2	45978	45716	43134	41208	41071	38896	35140	31047
Sum	90256	89683	85426	82237	82272	77234	70030	61885

5 Conclusion

The main work in this paper is to develop an integrated framework and method of pricing optimization which integrates and enhances the existing demand modelling, the retailers' pricing optimization and the generators' cost minimization methods. Based on this integrated framework and method, a computing simulation tool for ISO is developed to support the ISO to find the best acceptable and negotiable scheme to coordinate and balance conflict goals among the generators, retailers and customers. This ensures the fair distribution of cost and benefit among all groups in the market. The simulation results presented in Sect. 4 also shows that the simulation tool improves production efficiency of the day-ahead market as the gap between retailers' bought and sold electricity tends to be zero. It has been observed that the balanced mechanism shown in Sect. 3 is useful in managing the risk of increased production cost. Under the administration of ISO, retailers and generators afford part of customers' increased bill by reducing the MCP and sell price. But this paper also needs to be improved in some aspects. Firstly, it does not consider the gaming behaviour among generators when they report generation information to ISO. In this regard, the extension of considering which generators are able to game the ISO by reporting wrong production information under the proposed simulation tool is worth investigating in future. Secondly, the balance mechanism needs to be improved. A constitution is drawn up in balanced mechanism. Is the constitution fair enough to enforce a genuine market's participants so that their overall objectives may be maximally achieved? This problem can be formulated into the framework of n-person games. But it is hard or impossible to find a solution (the Nash arbitration value is well defined and unique). Then a class of solutions for group decision problems might be easier, in which each group's utility function over a decision space is assumed to be known for ISO [16]. Using decision-making method to enhance the balanced mechanism for ISO is another work in the future.

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