Research on the Collaborative Clearing Model of Ancillary Service and Electric Energy Market

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Abstract. There is a coupling relationship between the ancillary service market and the electric energy market. The joint clearing mechanism between the ancillary service market and the electric energy market is one of the urgent problems in the electric power development and electric power market construction. This paper studies the collaborative clearing mechanism of the frequency modulation market and reserve and electric energy market. Firstly, the separation sequence method and collaborative optimization method in CAISO power market are introduced, and the advantages and disadvantages of these two ancillary service clearing methods are compared and analyzed. Finally, the rationality and effectiveness of the above analysis are verified by an example, and the corresponding suggestions on the way of clearing should be adopted in the construction of power market are put forward.

1. Introduction

Power ancillary services refer to the services provided by power generation companies, grid operating companies and power users to maintain the safe and stable operation of the power system and ensure the quality of power, in addition to normal power production, transmission and use, including peak regulation, frequency regulation, and backup and other services. Ancillary services are the basis to ensure the safe and reliable operation of the power system. With the large-scale integration of renewable energy into the grid, the power system's demand for power flexibility resources such as frequency modulation, backup, and ramp has increased significantly. The power ancillary service market is an important trading platform to ensure the flexibility of the power system and an indispensable function in the perfect electricity market. In the context of a new round of electricity reform, China has gradually begun to build an ancillary service market in the initial stage of electricity market reform [1]. The ancillary service products purchased in the ancillary service market mainly include regulated reserve and operation reserve, and some other ancillary service types, including black-start, reactive power support and voltage control, etc. These ancillary services are generally not purchased on the market, and must be guaranteed by the power system operator and the resources that provide these services by signing a medium and long-term contract.

Therefore, for the construction of the electricity market, the joint clearing mechanism of the frequency modulation, reserve ancillary service market and the electric energy market is one of the problems that need to be solved urgently in the development of electricity and the construction of the electricity market. This paper first compares and analyzes the similarities and differences between the clearing
mechanism of the electric energy market and the ancillary service market in different power markets. Then a collaborative clearing model for the power market is proposed after comparing clearing methods. Finally, it builds a calculation example to analyze the feasibility and advantages of the proposed scheme.

2. Analysis of collaborative clearing mechanism of ancillary service market

At present, the power markets around the world are mainly represented by the centralized power market represented by CAISO and PJM in the United States and the decentralized power market represented by bilateral transactions in the UK. The optimization goal of the centralized power market is to maximize social welfare, while the optimization goal of the decentralized power market is the lowest dispatch cost and the lowest ancillary service cost. The main and ancillary joint coordination and optimization are carried out through centralized competition to maximize social welfare, and the market organization is relatively simple [2]. Therefore, this article takes the US CAISO [1] and PJM [3] markets as a reference to mainly study the collaborative mechanism under the centralized power market. Table 1 shows the comparison between the US CAISO and PJM market ancillary service mechanisms.

| Ancillary service market | US CAISO | US PJM |
|--------------------------|----------|--------|
| Ancillary service varieties | Frequency modulation | Frequency modulation | Frequency modulation |
|                          | Voltage regulation | Reactive power reserve | Reactive power supply |
|                          | Reserve | Voltage control | Voltage control |
|                          | Black-start | Spinning reserve | Synchronous reserve |
|                          | Else | Non-spinning reserve | Asynchronous reserve |
|                          | Flexible climbing products | Black-start | Black-start |
| Frequency modulation trading mechanism | Up frequency modulation | Limited energy |
| Transaction type | Down frequency modulation | |
| Joint clearing | Day-ahead+ Real-time | Real-time |
| Settlement method | Yes | Yes |
|                  | Real-time energy price | Marginal price |
| Reserve trading mechanism | Spinning reserve | Synchronous reserve |
| Reserve type | Non-spinning reserve | Asynchronous reserve |
| Response time | 10 min | 10 min |
| Transaction type | Day-ahead quotation clearing | |
| Settlement method | Clearing call within the day | Real-time |
|                  | Marginal price | Marginal price |
|                  | Real-time energy price | Real-time energy price |

3. Ancillary service market clearing model

Take the electricity market history of CAISO in the United States as an example, in a competitive centralized electricity market, ancillary services are purchased by the system operator/market manager as a single buyer. There are two ways to purchase: separate sequence method and collaborative optimization method.

3.1. Separate sequence method

The separation sequence method separates the energy transaction from the purchase of ancillary services. Each ancillary service product forms a single market separately, and the clearing sequence is determined according to the quality or response speed of the product. The CAISO electricity market
had been purchasing ancillary services by the separate sequence method since it went into operation in April 1998 until April 2009. The separation sequence method adopted in the early stage of the CAISO market did not consider the substitutability between ancillary services, but a special ancillary service—replacement reserve was used instead to deal with the load changes of two adjacent operation hours. The specific market rules and purchasing principles are as follows:

- Multi-product quotation: Each unit can submit quotations to any or all of the four different ancillary service products with different capacities and prices, but can only submit one quotation for capacity and price to a specific market.
- Quality order: Four different ancillary service products are cleared in order of quality: regulated reserve, spinning reserve, non-spinning reserve, and replacement reserve.
- Low-price bidding: Each ancillary service product wins the bid from the lowest quotation price to the highest quotation price, until the ancillary service demand is met. The final quotation price of the winning bid is the market clearing price (MCP, Market Clearing Price), and all quotations of the winning bid are cleared according to the MCP of the ancillary service.
- Partial selection: For quotations in MCP, if supply exceeds demand, part of its available capacity can be accepted. If there are multiple quotations in the MCP, they will be apportioned according to the proportion of the available capacity of each quotation.
- Capacity constraints: A unit can win bids in multiple ancillary service product markets. However, the total bid-winning capacity of the unit in each ancillary service market plus the energy plan cannot exceed its maximum available capacity.
- Climbing ability constraints: The capacity of the winning bid must meet the constraints of the climbing ability of a specific product within a specific climbing time.

The mathematical model of the above purchase principle can be expressed as:

$$\min \sum_{k=1}^{4} M_k D_k \quad \text{s.t.} \quad M_k = \max \{U_{i,k}, P_{i,k}\}, U_{i,k} = \begin{cases} 0, & X_{i,k} = 0 \\ 1, & X_{i,k} > 0 \end{cases}$$ \quad (1)

$$\sum_{k=1}^{4} X_{i,k} = D_k, \quad \sum_{k=1}^{4} X_{i,k} \leq \max \{0, C_i - E_i\}, 0 \leq X_{i,k} \leq \min \{Q_{i,k}, R_{i,k} S_k\}$$

Where, $N$ is the total number of units, $i$ is the unit number, $k=1,2,3,4$ respectively represent up-frequency modulation, spinning reserve, non-spinning reserve and substitute reserve; $D_k$ is the total demand capacity of auxiliary service $k$; $E_i$ is the energy plan of unit $i$; $C_i$ is the maximum output of unit $i$; $Q_{i,k}$ is the capacity quotation of unit $i$ for auxiliary service $k$; $P_{i,k}$ is the quoted price of unit $i$ for auxiliary service $k$; $R_{i,k}$ is the ramp rate of auxiliary service $k$ provided by unit $i$; $S_k$ is the climbing time required by auxiliary service $k$; $X_{i,k}$ is the quoted price of unit $i$ for auxiliary service $k$ accepted by the market; $M_k$ is the market clearing price of the auxiliary service $k$; $U_{i,k}$ is the participation coefficient of the auxiliary service $k$ provided by the unit $i$.

Although this method can achieve the lowest cost of each individual ancillary service, it does not necessarily ensure the lowest overall cost of purchasing all ancillary services. Therefore, in California’s electricity market, it is allowed to adopt higher-quality ancillary service products to meet the demand for lower-quality ancillary services. Under this rule, due to the existence of many different ancillary service alternatives, Liu Shucheng proposed the Rational Buyer’s Algorithm (Rational Buyer’s Algorithm) [4] in order to find an optimal solution to minimize the cost of MCP payment. The Rational Buyer’s Algorithm changes the demand constraint conditions of the four ancillary service products in the original purchase model from four equations to four inequalities, and realizes the substitutability among the ancillary services on the algorithm. Compared with the earlier separation sequence method, the separation sequence method based on the Rational Buyer’s Algorithm relaxes the demand constraints and helps to save the total purchase cost. When there are insufficient quotations for ancillary services in the market, reserve alternatives can be used to accept as much available quotation capacity as possible to eliminate or reduce the degree of quotation shortage. In the California electricity market, the separation sequence method based on the rationality algorithm has been used from 1999 to March 2009 [5]. The clearing model of separation order method based on the Rational Buyer’s Algorithm can be shown by equation (2). Compared with the originally designed
separation sequence method, the Rational Buyer’s Algorithm saves considerable purchase costs for the ancillary service market in California.

\[
\min \sum_{i=1}^{N} M_i D_k \quad \text{s.t.} \quad M_k = \max \{U_i^k, P_i^k\}, \quad U_i^k = \begin{cases} 0, & X_{i,k} = 0 \\ 1, & X_{i,k} > 0 \end{cases},
\]

\[
\sum_{i=1}^{N} X_{i,1} \geq D_1, \sum_{i=1}^{N} X_{i,2} \geq D_2, \sum_{i=1}^{N} X_{i,3} \geq D_3, \sum_{i=1}^{N} X_{i,4} \geq D_4, \sum_{i=1}^{N} X_{i,k} \leq \min \{0, C_i - E_i\}, 0 \leq X_{i,k} \leq \min \{Q_{i,k}, R_{i,k}, S_{i,k}\}
\]

The market rules of the separation sequence method are relatively simple and clear, and it is relatively easy to implement and operate. It is easy for market participants to understand the market results and discover potential problems, and raise questions and challenges to the market results; at the same time, market managers can easily find problems with the operation results and explain or correct the operation results to market participants.

However, the separation sequence method also has some insurmountable shortcomings, such as the inability to deal with the problem of network congestion. Therefore, the use of the separation sequence method must assume that there is no congestion in the system or auxiliary service area. In addition, the separation sequence method may result in price inversion, that is, under certain conditions, the lowest-quality substitute reserve price is higher than the price of other higher-quality auxiliary services, which is not conducive to maximizing resource allocation. More importantly, in a market with energy trading, there is a close coupling relationship between various auxiliary service products and energy trading. The provision of auxiliary services by the unit means that the unit cannot operate at full capacity, which will inevitably reduce the efficiency of the unit. In order to allow high-efficiency and low-cost units to provide auxiliary services, some low-efficiency and high-priced units must be deployed to provide energy, which may increase the price of energy.

3.2. Collaborative optimization method

In terms of clearing results, how much energy a unit provides and how many auxiliary services are kept in reserve are the best operating methods for the unit. Which units provide how much energy or how many auxiliary services to provide reserve, is the best operation mode of the system. The separation sequence method cannot solve this problem. Therefore, the electric energy and auxiliary services must be unified and collaborated optimization. For generator sets and controllable loads, their auxiliary service backup capacity and power generation capacity are mutually influential and closely related [6]. Therefore, since the redesigned power market system in California was put into production in April 2009, the collaborative optimization method has begun to replace the separation sequence method and become the new clearing method of CAISO.

The objective function of the collaborative optimization method is to minimize the total cost of purchasing energy, regulating reserve, spinning reserve and non-spinning reserve, and subject to the following constraints: The accepted energy plan for each unit must be greater than or equal to its minimum operating capacity limit; the sum of the accepted energy plan of each unit plus the accepted ancillary service capacity cannot exceed its maximum capacity limit; the total accepted energy of all units and the sum of various ancillary service capacities should meet the requirements of the system. The market rules and purchase principle of the simplified collaborative optimization method can be expressed by equation (3):

\[
\min \sum_{i=1}^{n} \text{EN}_i P_{1,EN} + \sum_{i=1}^{n} \text{RU}_i P_{1,RU} + \sum_{i=1}^{n} \text{SP}_i P_{1,SP} + \sum_{i=1}^{n} \text{NS}_i P_{1,NS},
\]

s.t. \( P_{\text{MIN}} \leq \text{EN}_i + \text{RU}_i + \text{SP}_i + \text{NS}_i \leq P_{\text{MAX}}, \)

\[
\sum_{i=1}^{n} \text{EN}_i = \text{Req}_E, \sum_{i=1}^{n} \text{RU}_i = \text{Req}_R, \sum_{i=1}^{n} \text{SP}_i = \text{Req}_S, \sum_{i=1}^{n} \text{NS}_i = \text{Req}_N
\]
Where, $EN_i$ is the energy of the purchased unit $i$; $RU_i$ is the regulated reserve for the purchased unit $i$; $SP_i$ is the spinning reserve for the purchased unit $i$; $NS_i$ is the non-spinning reserve for the purchased unit $i$; $P_{en_i}$, $P_{ru_i}$, $P_{sp_i}$ and $P_{ns_i}$ is the quotation of unit $i$ for energy, regulated reserve, spinning reserve and non-spinning reserve; $P_{MIN_i}$ is the minimum operating capacity limit of unit $i$; $P_{MAX_i}$ is the maximum capacity limit of unit $i$; $R_{eqEN_i}$, $R_{eqRU_i}$, $R_{eqSP_i}$ and $R_{eqNS_i}$ are system requirements for energy, regulated reserve, spinning reserve and non-spinning reserve respectively.

In the separation sequence method, the MCP of a certain product is the highest quotation price accepted for the product, and the MCP of the collaborative optimization method is the marginal price, that is, the total quotation cost increased by adding 1 MW of the product demand. The Rational Buyer’s Algorithm described in Section 2.1 is also applicable to the collaborative optimization method. In this way, the three auxiliary service demand constraint equations in equation (3) can be rewritten into three inequalities as shown in equation (4):

$$\sum_{i=1}^{n} RU_i = Req_{RU} + \sum_{i=1}^{n} SP_i = Req_{RU} + Req_{SP}$$

$$\sum_{i=1}^{n} RU_i + \sum_{i=1}^{n} SP_i + \sum_{i=1}^{n} NS_i = Req_{RU} + Req_{SP} + Req_{NS}$$

In addition, the collaborative optimization method can also deal with the problem of network congestion. Usually, the vertical demand purchase model with operating reserve between the two regions is shown in equation (5):

$$\min \sum_{i=1}^{I} Pen_{i,j}EN_{1,i} + Por_{1,i}OR_{1,i} + \sum_{j=1}^{J} Pen_{2,j}EN_{2,j} + Por_{2,j}OR_{2,j}$$

$$s.t. \sum_{i=1}^{I} Pen_{1,i} - f_{1,2} = Load_1, \sum_{j=1}^{J} Pen_{2,j} + f_{1,2} = Load_2, f_{1,2} \leq OTC,$$

$$Pen_{1,i} + Por_{1,i} \leq P_{MAX1,i}, Pen_{2,j} + Por_{2,j} \leq P_{MAX2,j}, \sum_{i=1}^{I} Por_{1,i} \geq Req_{OR1}, \sum_{j=1}^{J} Por_{2,j} \geq Req_{OR2}$$

Where: $I$ and $J$ are the number of units in area 1 and area 2 respectively; $Pen_{1,i}$, $Pen_{2,j}$ are the energy prices of purchasing unit $i$ in area 1 and unit $j$ in area 2 respectively; $EN_{1,i}$, $EN_{2,j}$ are the energy of purchasing unit $i$ in area 1 and unit $j$ in area 2 respectively; $Por_{1,i}$, $Por_{2,j}$ are the operating reserve prices of purchasing unit $i$ in area 1 and unit $j$ in area 2 respectively; $OR_{1,i}$, $OR_{2,j}$ are the operating reserve requirements of purchasing unit $i$ in area 1 and unit $j$ in area 2 respectively; $f_{1,2}$ is the power flow between area 1 and area 2; $Load_1$ and $Load_2$ are the load demand of area 1 and area 2 respectively; $OTC$ is the transmission capacity between area 1 and area 2; $P_{MAX1,i}$, $P_{MAX2,j}$ are the maximum capacity of purchasing unit $i$ in area 1 and unit $j$ in area 2 respectively; $Req_{OR1}$ and $Req_{OR2}$ are the operating reserve requirements of area 1 and area 2 respectively.

4. Analysis of examples

In this section, the example analysis will be performed to compare the characteristics of the separation sequence method and the collaborative optimization method. The clearing model of the calculation example is a linear model, and MATLAB software is used to optimize the model and analyze the clearing model established. Taking the installed capacity data of a certain area as an example, the annual installed capacity of this area is about 5000MW, the maximum single unit capacity is 175MW, and the load level is about 2500MW.

4.1. Separation sequence method

The declared capacity and prices of the 4 units in the area for different auxiliary services are shown in Table 2. For the sake of simplification, it is assumed that the energy plan of all units is zero and does not participate in the replacement reserve, and the climbing ability of each unit is infinite. The
deterministic method is used to determine the capacity requirements of each ancillary services. The market’s capacity requirements for the three ancillary services are shown in Table 3. When an offer in a certain market is accepted, the actual capacity of the same unit in the next lower quality market will be adjusted accordingly. Similarly, the clearing process of spinning reserve and non-spinning reserve is the same as the above process. Table 4 show the results of purchasing ancillary services using the separate sequence method. Although this approach will minimize the possible cost of each ancillary service, it does not necessarily ensure that the overall cost of purchasing all ancillary services is minimized.

### Table 2. Offer of ancillary services in the separation sequence approach (MW).

| Unit  | Regulated reserve | Spinning reserve | Non-spinning reserve | Maximum capacity | Energy plan |
|-------|-------------------|------------------|----------------------|------------------|-------------|
| Unit 1| (50.3¥)           | (50.8¥)          | (50.5¥)              | 90               | 0           |
| Unit 2| (110.4¥)          | (110,14¥)        | (110,10¥)            | 130              | 0           |
| Unit 3| (80,5¥)           | (80,5¥)          | (80,9¥)              | 120              | 0           |
| Unit 4| (130,6¥)          | (130,9¥)         | (80,9¥)              | 160              | 0           |

### Table 3. Requirement of ancillary services in the separation sequence approach (MW).

| Regulated reserve | Spinning reserve | Non-spinning reserve | Total reserve demand |
|-------------------|------------------|----------------------|----------------------|
| 220               | 150              | 100                  | 470                  |

### Table 4. Purchase result of the separation sequence approach.

| Regulated reserve/MW | Spinning reserve/MW | Non-spinning reserve/MW | Total |
|----------------------|---------------------|-------------------------|-------|
| Unit 1               | 50,3¥               | 40,8¥                   | 90    |
| Unit 2               | 110,4¥              | 0                       | 110   |
| Unit 3               | 60,5¥               | 60,5¥                   | 120   |
| Unit 4               | 0                   | 50,9¥                   | 150   |
| Total capacity       | 220                 | 150                     | 470   |
| Clearing price/¥     | 5                   | 9                       | 7     |
| Quotation fee/¥      | 890                 | 1070                    | 2660  |
| Clearing fee/¥       | 1100                | 1350                    | 3450  |

### Table 5. Purchase result of the separation sequence approach based on rational buyer’s algorithm.

| Regulated reserve | Spinning reserve | Non-spinning reserve | Total |
|-------------------|------------------|----------------------|-------|
| Unit 1            | 50,3¥            | 0                    | 80    |
| Unit 2            | 110,4¥           | 0                    | 110   |
| Unit 3            | 40,5¥            | 80,5¥                | 120   |
| Unit 4            | 130,6¥           | 0                    | 160   |
| Total capacity    | 330               | 80                    | 470   |
| Clearing price/¥  | 6                 | 5                     | 7     |
| Quotation fee/¥   | 1570              | 400                   | 2330  |
| Clearing fee/¥    | 1980              | 400                   | 2800  |

Modify the equation according to the Rational Buyer’s Algorithm, and through the evaluation of different price combinations one by one, a set of price combinations that minimize the payment cost are finally found. The results are shown in Table 5. By purchasing higher-quality ancillary service products to replace lower-quality products, the clearing price of spinning reserve was reduced from 9
Although the purchase amount of regulated reserve has been increased, the total clearing fee has been changed from 3150¥ to 2800¥, saving 350¥.

### 4.2. Collaborative optimization method

Take a simplified example of centralized quotation for energy and auxiliary services for analysis, and set the system's demand for energy and auxiliary service reserve capacity respectively. The basic data of the clearing model based on the collaborative optimization method are shown in Table 6 and Table 7, which are quotations for energy plans and three auxiliary service capacities of 5 units in the area and system’s demand for energy and auxiliary service reserve capacity respectively. The solution is carried out by linear programming, and the results are shown in Table 8.

**Table 6.** Offer of energy and ancillary services in the collaborative optimization approach.

| Energy plan/MW | Regulated reserve/MW | Spinning reserve/MW | Non-spinning reserve/MW | Minimum capacity/MW | Maximum capacity/MW |
|----------------|----------------------|---------------------|------------------------|---------------------|---------------------|
| Unit 1 (240,22¥) | (30,4¥) | (30,1¥) | (30,6¥) | 60 | 240 |
| Unit 2 (240,30¥) | (30,9¥) | (30,10¥) | (30,7¥) | 60 | 240 |
| Unit 3 (240,33¥) | (30,5¥) | (30,15¥) | (30,13¥) | 60 | 240 |
| Unit 4 (240,42¥) | (30,7¥) | (30,8¥) | (30,9¥) | 60 | 240 |
| Unit 5 (240,51¥) | (30,8¥) | (30,7¥) | (30,11¥) | 60 | 240 |

**Table 7.** Requirement of energy and ancillary services in the collaborative optimization approach.

| Energy plan/MW | Regulated reserve/MW | Spinning reserve/MW | Non-spinning reserve/MW |
|----------------|----------------------|---------------------|------------------------|
| 750 | 55 | 55 | 55 |

**Table 8.** Purchase result of the collaborative optimization approach.

|                   | Energy plan/MW | Regulated reserve/MW | Spinning reserve/MW | Non-spinning reserve/MW | Minimum capacity/MW |
|-------------------|----------------|----------------------|---------------------|------------------------|---------------------|
| Unit 1            | 240,22¥        | 0                    | 0                   | 0                      | 240                 |
| Unit 2            | 215,30¥        | 0                    | 0                   | 25,7¥                  | 240                 |
| Unit 3            | 175,33¥        | 30,5¥                | 0                   | 0                      | 205                 |
| Unit 4            | 60,42¥         | 25,7¥                | 25,8¥               | 30,9¥                  | 140                 |
| Unit 5            | 60,51¥         | 0                    | 30,7¥               | 0                      | 90                  |
| Total capacity/MW | 750            | 55                   | 55                  | 55                     | 915                 |
| Clearing price/¥  | 33             | 7                    | 8                   | 9                      |                     |
| Quotation fee/¥   | 23085          | 325                  | 410                 | 445                    | 24265               |
| Clearing fee/¥    | 26370          | 385                  | 440                 | 495                    | 27690               |

Different from the separation sequence method in the previous section, the market clearing price in the collaborative optimization method is the marginal price of the product, that is, the total quotation cost increased by adding 1 MW of the product, which is also the dual variable of the demand constraints generated by the linear programming program. It can be seen from Table 8 that the market clearing price of the energy plan is 33¥, while the quotation of Unit 4 is 42¥, and the quotation of Unit 5 is 51¥. Each unit has been accepted as an energy quote of 60MW because it has a minimum operating capacity constraint of 60MW. If the quotation of the unit is closer to the operating cost of the unit, it is unreasonable to pay Unit 4 and Unit 5 at the market clearing price of 33 ¥. In order to ensure that
Units 4 and 5 can recover their operating costs, they will pay according to their quotations. Therefore, the total cost for the system operator to purchase the energy required by the system is 26370¥.

The reserve substitution (Rational Buyer’s Algorithm) described above can also be used for collaborative optimization. The results obtained by linear programming are shown in Table 9. From Table 8 and Table 9, it can be seen that the quotation fee of the collaborative optimization method that allows reserve substitution has been reduced from 24265¥ to 24195¥, but the purchase cost has been increased from 27745¥ to 27855¥.

|   | Energy plan/MW | Regulated reserve/MW | Spinning reserve/MW | Non-spinning reserve/MW | Minimum capacity/MW |
|---|----------------|----------------------|---------------------|-------------------------|---------------------|
| Unit 1 | 240.22¥ | 0 | 0 | 0 | 240 |
| Unit 2 | 240.30¥ | 0 | 0 | 0 | 240 |
| Unit 3 | 150.33¥ | 30.5¥ | 0 | 0 | 180 |
| Unit 4 | 60.42¥ | 30.7¥ | 30.8¥ | 15.9¥ | 135 |
| Unit 5 | 60.51¥ | 30.8¥ | 30.7¥ | 0 | 120 |
| Total capacity/MW | 750 | 90 | 60 | 15 | 915 |
| Clearing price/¥ | 33 | 9 | 9 | 9 | — |
| Quotation fee/¥ | 23010 | 600 | 450 | 135 | 24195 |
| Clearing fee/¥ | 26370 | 810 | 540 | 135 | 27855 |

5. Conclusion

This paper analyzes the characteristics of the ancillary service market in each regional power market, and studies the coupling mechanism between the ancillary service and the electric energy market as well as the joint clearing method of the electric energy market and the ancillary service market. Taking the California power market as an example, this paper focuses on the analysis of two different clearing methods adopted by the CAISO power market, and compares the advantages and disadvantages of them. Through calculation examples, the advantages and disadvantages of the two clearing models are compared, and suggestions are made for the reference of the ancillary service market and the electricity energy market in the construction of the future electricity market.

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