A Global Optimization Approach to Ancillary Service Procurement

Juan-Juan Wang a,b, Wen-Lei Zhao a,b, Wei-Dong Li b, Yun-Li Zhao b

Abstract

A global optimization approach is put forward in the paper, which can minimize the total cost when the demands of ancillary services have been met. Based on the replacement of various of ancillary services, such as AGC, spinning reserve, non-spinning reserve and standby reserve. The highest-quality ancillary service is first met as various of ancillary services are bidding in the same time. Case studies show that the method is effective and practical, and can save more compared with the sequence approach.

© 2011 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of Harbin University of Science and Technology. Open access under CC BY-NC-ND license.

Keyword: auxiliary service; bidding method; replacement

1. Introduction

The power industry is a typical monopoly trade naturally in the world. Its total generation costs will decrease when the power industry acts as a sort of monopoly, because of economies of scale. But in recent years, the advent of advanced small-sized generate electricity, such as micro turbine generation and wind power generation, the monopoly advantage of the large-sized power plants has been receded. In such circumstance, in order to increase the vitality of the power industry, raise its benefit and decrease electricity price, most countries in the world are pursuing the power market reform. In the normal running of power system, in the interest of consummating the transmission and energy transaction, and ensuring
system safety and the power quality, the ancillary service market which is penetrated in each power trading session is necessary except for the energy market. That is, ancillary services can maintain the security of the power system, improve its riding quality, and decrease the prices of peak loads throughout the electricity production, transmission and utilization.

Ancillary services[1] include shaving peak, frequency regulation, reserve, reactive power supporting, black-start and all that. Because of diversity and complexity of ancillary services and the interchangeability among them, the tender and exchange of ancillary services is one of hot issues in today's research. The paper holds the hypothesis that there are four ancillary services in an ancillary service market, which are automation generation control(AGC), spinning reserve, non-spinning reserve and standby reserve. AGC is also called the second frequency regulation. When the market supply and demand imbalances, the unbalancing value is the first regulated by the governor which will regulate the engine speed automatically. Then, the real-time unbalancing will be regulated by AGC, which command is issued by the dispatching center and executed by AGC generators. Reserve is the reserved capacity or electricity which is supplied by generators or loads for assuring the security and reliability of power supply. Although having different functions, the essence of reserve and AGC are power electricity.

2. The Setting of Market Rules

The tender and exchange of ancillary services correlate closely to the ancillary service market rules. In the paper the rules are as follows:

(1) Many tenders. A bidder can bid for the four ancillary services at the same time, and the tender with different capabilities and prices is valid. But to a market, a bidder just can submit a bid scheme with a capacity and a price.

(2) The order of ancillary service quality standards is AGC, spinning reserve, non-spinning reserve and standby reserve. AGC is the finest quality, and so on. The demand of high-quality service is met at first, then low-quality service. A high-quality service can replace a low-quality one.

(3) Tenderers independently submit a bid for competition and the transaction price is uniform. In any kind of service market, independent system operator(ISO) determines the successful tenderers in the bid order from low to high until the demand of the period concerned has been met. The bid of the last successful tenderer is the marginal clearing price(MCP) of the period concerned and all successful tenderers will be settled in the price. The tenderers won’t be successful when their bids are higher than MCP.

(4) Capacity constraints. The tenderer can be successful in two kinds or above markets at the same time, but the total successful capacity can’t exceed its total available capacity which is measured by the technical performances of units and power schemes. Units which are at much lower bid may fully output as necessary.

3. The Sequence Approach

Californian is one of regions which earlier make ancillary services to commercialize. Its first bidding method in the ancillary service market is the sequence approach[2].

The operation of the approach is explained by an example of 4 units. The bids of generators for every kind of ancillary service market, maximum capacity limits of units and the outputs project of generators are shown in Table1. The demands of ancillary services are shown in Table 2.
Table 1. The bids of ancillary services

| AGC      | Spinning reserve | Non-spinning reserve | Standby reserve | The capacity limits | The outputs of generators |
|----------|------------------|----------------------|-----------------|---------------------|--------------------------|
| Bids     | (MW, $)          | (MW, $)              | (MW, $)         | MW                  | MW                       |
| Unit 1   | (60, 5)          | (60, 10)             | (60, 5)         | 90                  | 0                        |
| Unit 2   | (100, 3)         | (100, 2)             | (100, 10)       | 160                 | 0                        |
| Unit 3   | (120, 4)         | (120, 4)             | (120, 4)        | 160                 | 0                        |
| Unit 4   | (80, 2)          | (80, 5)              | (80, 2)         | 100                 | 0                        |

Table 2. The demands of ancillary services

| AGC | Spinning reserve | Non-spinning reserve | Standby reserve | Total |
|-----|------------------|----------------------|-----------------|-------|
|     | 200              | 100                  | 100             | 500   |

In the example, the climbing speeds of the four units are assumed to meet the requirements completely. The bids are assessed firstly and the order of the units is shown in Table3. The sum of these capacities is the cumulate capacity. The successful capacity of each unit is determined according to the order of tender prices and the actual capacities available until the total demand of 200MW has been met. The bid of the last successful unit is MCP of AGC market (MCP=$4 in Table3).

Table 3. The tender for AGC market(The demands of 200MW)

| The order of prices | Units | Bidding price($) | Bidding capacity(MW) | Capacity available (MW) | Cumulate capacity(MW) | Successful capacity(MW) |
|---------------------|-------|------------------|----------------------|------------------------|-----------------------|-------------------------|
| 1                   | Unit4 | 2                | 80                   | 80                     | 80                    | 80                      |
| 2                   | Unit2 | 3                | 100                  | 100                    | 180                   | 100                     |
| 3                   | Unit3 | 4                | 120                  | 120                    | 200                   | 20                      |
| 4                   | Unit1 | 5                | 60                   | 60                     | 200                   | 0                       |

When a bidding unit has been successful in AGC market, its bidding capacity for the next market will be adjusted. In the order of spinning reserve, non-spinning reserve and standby reserve, this step is repeated, as shown in Table4 - Table6.

Table 4. The tender for spinning reserve market(The demands of 100MW)

| The order of prices | Units | Bidding price($) | Bidding capacity(MW) | Capacity available (MW) | Cumulate capacity(MW) | Successful capacity(MW) |
|---------------------|-------|------------------|----------------------|------------------------|-----------------------|-------------------------|
| 1                   | Unit4 | 3                | 80                   | 20                     | 20                    | 20                      |
| 2                   | Unit2 | 4                | 120                  | 140                    | 100                   | 80                      |
| 3                   | Unit3 | 6                | 100                  | 60                     | 100                   | 0                       |
Table 5. The tender for non-spinning reserve market (The demands of 100MW)

| The order of prices | Units | Bidding price($) | Bidding capacity(MW) | Capacity available (MW) | Cumulate capacity(MW) | Successful capacity(MW) |
|---------------------|-------|------------------|----------------------|------------------------|-----------------------|------------------------|
| 1                   | Unit1 | 1                | 60                   | 90                     | 60                    | 60                     |
| 2                   | Unit2 | 2                | 100                  | 60                     | 100                   | 40                     |
| 3                   | Unit3 | 4                | 120                  | 60                     | 100                   | 0                      |
| 4                   | Unit4 | 5                | 80                   | 0                      | 100                   | 0                      |

Table 6. The tender for standby reserve market (The demands of 100MW)

| The order of prices | Units | Bidding price($) | Bidding capacity(MW) | Capacity available (MW) | Cumulate capacity(MW) | Successful capacity(MW) |
|---------------------|-------|------------------|----------------------|------------------------|-----------------------|------------------------|
| 1                   | Unit4 | 2                | 80                   | 0                      | 0                     | 0                      |
| 2                   | Unit3 | 4                | 120                  | 60                     | 60                    | 60                     |
| 3                   | Unit2 | 5                | 60                   | 30                     | 90                    | 30                     |
| 4                   | Unit1 | 10               | 100                  | 20                     | 100                   | 10                     |

Although the method can make the cost of each market minimum, the total costs of all markets may not be minimum. In the above example, the cost of standby market is going up because the 10MW successful capacity of unit 2 leads its MCP grows from $5 to $10. The MCP of the standby reserve market and the total market cost will decrease if the 10MW of unit 2 is replaced by 10MW of other better-quality ancillary service market. So, when ancillary service market rules are made, a successful capacity of a better-quality market is permitted to replace one of a lower-quality market, and the alternatives are various.

4. The Global Optimal Search Algorithm

The sequence approach is simple, but decreases market efficiency and makes better-quality service price and lower-quality service price upside down. In order to solve the problem, a new tender and exchange method of ancillary services is proposed in the paper, which uses a way of globally optimizing and can minimize the cost when the demand of ancillary service has been met.

The objective function of the algorithm is

$$\min(P_1 * C_1 + P_2 * C_2 + P_3 * C_3 + P_4 * C_4)$$  \hspace{1cm} (1)$$

The constraint functions are

$$C_i \geq D_i$$ \hspace{1cm} (2)

$$(C_1 + C_2) \geq (D_1 + D_2)$$ \hspace{1cm} (3)$$
\[(C_1 + C_2 + C_3) \geq (D_1 + D_2 + D_3)\]  \hspace{1cm} (4)

\[(C_1 + C_2 + C_3 + C_4) = (D_1 + D_2 + D_3 + D_4)\]  \hspace{1cm} (5)

Where \(C_1, C_2, C_3, C_4\) are the successful capacity in AGC market, spinning reserve market, non-spinning reserve market and standby reserve market respectively. \(D_1, D_2, D_3, D_4\) are the demands of the above markets. \(P_1, P_2, P_3, P_4\) are MCP of the above markets.

The principle of the algorithm is to analyze and optimize various possible MCPs combinations. The number of combinations is limited because (a) The number of ancillary services in any market is limited. (b) The bidding number of each market is limited.

At first the lowest price will be searched among all bidding prices. The outputs corresponding to the lowest price are bought in order to meet the demands of the ancillary service which are corresponding to the price. The redundant outputs can be used to meet the demands of lower-quality services. Then sub-prime price will be searched and so on until the demands of all ancillary services have been met. A generation company will buy higher-quality service when the bidding prices of various services are same. If the demands of higher-quality service have been met, a higher-quality service is forbidden to replace a lower-quality one to avoid rising the purchase costs of ancillary services.

According to the above algorithm flowchart, (1) the lowest price in all units is $1 of unit 1, the corresponding service is non-spinning reserve and its bidding capacity is 60MW. The demands of non-spinning reserve and standby reserve are 200MW, so the 60MW is successful capacity. (2) The sub-prime price is $2, the successful bidding capacities are 100MW non-spinning reserve of unit 2, 80MW AGC capacity of unit 4, 80MW standby reserve of unit 4. There is a principle that a higher-quality service has the priority of being successful when the bidding prices are same. Therefore, the 80MW AGC capacity of unit 4 is successful at first. At that time, the demands of non-spinning reserve and lower-quality services is 140MW which is bigger than 100MW non-spinning reserve of unit 2, so the 100MW is successful. The capacity limit of unit 4 is 100MW, 80MW of which has won the bidding, so the successful capacity upper limit of standby reserve of unit 4 is 20MW which can win the bidding because the successful capacity is smaller than the demands. Unit 4 isn’t considered again in the ordering of bidding prices because its capacity has been used up. (3) And so on, the 60MW AGC capacity of unit 2 can win the bidding. The fourth capacity which win the bid are the 120MW AGC capacity, and the 40MW spinning reserve of unit 3. The fifth capacities which win the bid are the 20MW standby reserve of unit 1.

5. Conclusions

Compared with the sequence approach, the global optimal search algorithm can get the global optimized solution and decrease the purchase costs when the market rules are followed. In the current ancillary service market, the average number of bidders is less than 100, and the kinds of ancillary services in any market are less than 50. It is supposed that the number of bidders and bidding prices double, the combination of prices will be \(2 \times 10^4\). Even then, the search algorithm proposed by the paper also meets the requirement of the real-time calculation completely.
References

[1] Zeng Ming. *The theory and its application of ancillary services in the electric market*. Beijing: China Electric Power Press, 2003.

[2] Yenren Liu, Ziad Alaywan, Mark Rothleder.. A rational buyer’s algorithm used for ancillary service procurement. *Power Engineering Society Winter Meeting, 2000 IEEE*, vol.27, pp.855-860, 2000.