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Research on the Load Dispatching Model to Deal with the Uncertainty of Wind Power

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Abstract: High penetration of wind power brings a great challenge to the power system scheduling mode and technologies. Existing researches show that load resources would have great potential and economic benefits on this aspect. However, it will cause a complex control problem when a large number of loads participate in active power scheduling. Therefore, How to establish an effective and feasible load scheduling model is necessary.

Based on the multi-agent technology, the interaction mechanism between demand response loads participate in the dispatching operation and the specific load dispatching model are studied in this paper. First, the 3-layered architecture of 'control centre's decision-making layer, agent-coordination layer, local load response layer' is established, and the working mechanism of load agents is designed; Then, the decision-making model of the load agent is established, and a bidding strategy for the global optimum is put forward to the power company based on the game theory; By analysing the scheduling cost of different adjustable resources which can be generators or loads, the power company will make decisions for minimizing their scheduling costs; On this basis, the transaction process between the load agents and the dispatching centre is designed. Finally, examples on the IEEE 39-bus model demonstrate the validity of the model and strategy proposed in this paper. The results show that, with the multi-agent load dispatching mechanism, the load resources can be adequately utilized and the generator reserve is decreased obviously, the cost of dispatching system is reduced effectively, and a win-win status of the power company and load agents is achieved.

1. INTRODUCTION

It is important and urgent to develop renewable energy due to the shortage of energy resources, climate change, environmental pollution and other factors. However, wind power and other renewable energies have some 'unfriendly' features such as fluctuations volatile, intermittency, anti-peaking and hard-dispatching, which make the traditional 'power tracking load' dispatching mode unsuitable. To deal with this challenge, the coordinated interaction among power sources, power grid and load is studied The interaction can improve dynamic power balance ability of power system and increase the efficiency of energy utilization, which is an important development direction of the smart grid (Yao Jianguo et al., 2012, Zhang Xin et al., 2008, Duncan S. et al., 2011, Tan Zhongfu et al., 2009).Researches on demand response load dispatching have been carried out worldwide. Literature (Wang Beibei et al., 2013) proposes the concept of load dispatching, and the integrated dispatching model of generators and loads is established, considering the wind power, excitative load, interruptible load and price response load. In addition, the heuristic dynamic programming algorithm is used to solve the mode; literature (Liu Xiao, 2013) builds a dispatching mode taking account of users' interaction of the smart grid. In this mode, the consumption patterns and choices willingness of users are considered through a consumer psychology method, the interruptible load and the alternate reserve is optimized coordinately, the dispatch plan has been made on the basis of comprehensive measurement of interests of all parties and the selection of the optimal price of TOU optimal capacity of interruptible load. The literature (Kah-hoe Ng et al,. 1998) establishes one day ahead dispatching mode considering both the wind power and the demand response, in which the fluctuations and random of wind power has been especially considered, and the cost of the interruptible load is take into account in the objective function. In literature (Zhang Senlin et al., 2010) a chance constrained model with wind power and price based and incentive based demand response is established, in which the uncertainty of the wind power is considered and the stochastic particle swarm algorithm is used to solve the model. The literature (EricSortomme et al., 2012) proposes profit-based load management mode in order to take into account the interests of the power companies, and to consider the energy return model of the interruptible load. The literatures above made a study on the dispatching models and algorithms of demand response, but the coordination control mechanism of vast and diverse demand response resources remains to be further studied.

It is difficult to control the demand response resources because there are many ways when loads participate in demand response and its single capacity is small. With the advantages of independent learning and decision-making functions, multi-agent technology provides an ideal way for dispatching various and massive demand response resources. The literature (Liu Meizhao et al., 2005) makes a review for the basic model, learning algorithms, market rules and other factors of agent-based market simulation, and the directions with development potential are discussed. Literatures (Song Yiqun, 2005, Chen Haoyong, 2008) respectively propose Q-learning algorithm and faith-based learning algorithm for multi-agent market simulation. The literatures above prove that it is feasible for the multi-agent technology to be used in the electricity market. In this paper, for the problem of the power imbalance caused by the uncertainty of the wind power, the overall architecture of load dispatch based on multi-agent technology is proposed, the working mechanism of load agents is designed, and the specific scheduling model and the decision algorithm are studied.

2. LOAD DISPATCHING ARCHITECTURE BASED ON MULTI-AGENT

The load agent is a middle institution to coordinate large number of small-scale demand response resources and dispatching and control of power grid. It shows a comprehensive external characteristic of the load group to the dispatching and trading centre while it coordinates demand response resources with different types internally, and it makes optimal decision for some particular optimization goal. The dispatching architecture based on multi-agent technology is divided into three layers: dispatching control layer, agent coordination layer and local response layer, which is shown in Fig. 1.

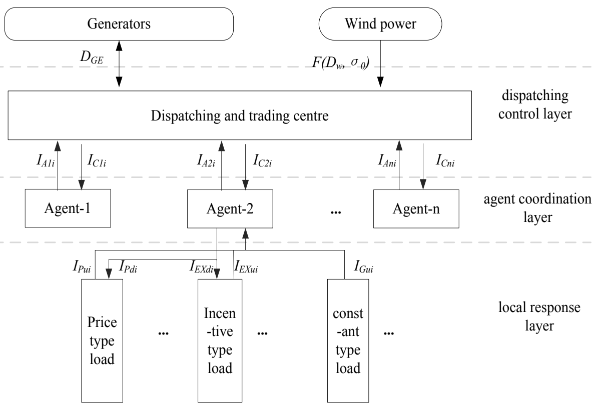

Fig. 1 The dispatching architecture based on multi-agent

In Fig. 1, $F(\mu,\sigma)$ represents probability distribution function of the wind power output; D_{GE} represents the generation output of power system; I_{CNi} and I_{ANi} respectively represents the system information got from the power dispatching centre and the bidding information of Agent N in the period i; I_{Pui}, I_{EXui} and I_{Gui} respectively represents the electricity information of the price type load, the incentive type load and the constant type load; I_{Pdi} and I_{EXdi} are respectively the control information of agent for the price type load and the incentive type load. This working mechanism of the load agent is designed as follows:

a. According to the different types of the load participated in demand response, the load in same agent could be divided into the price type load, the incentive type load and the constant type load. The constant type load doesn't response to the control orders of the load agent;

b. The load agents provide ancillary services to the grid in a bidding way. After obtaining dispatching and control information, the agent takes the maximum profit as a target to bid against others. The bidding content includes load power adjustment and corresponding compensation price. After bidding, the agent adjusts load power by the price and incentive;

c. While adjusting the active power, load prices in different agents may be different due to different bidding results;

d. There is no need to communicate mong agents, but the load agent needs to communicate with dispatching and trading centre as well as the local loads. The load agents have independent learning and decision-making functions;

e. The dispatching and trading centre deals with all agents with a uniform compensation price, and there are uniform limits of compensation price $L_{\min}$ and $L_{\max}$ for the bidding process of all the load agents.

3. DISPATCHING MODE BASED ON LOAD AGENTS

3.1 The decision making model of load agents

Suppose the bidding content of each load agent is a linear function about power adjustment and compensation prices, and the bidding strategy of agent k can be expressed as:

$$L_{ik} = A_{ik}\Delta D_{ik} + B_{ik} \tag{1}$$

Where, the subscript i denotes period i; $\triangle D_{ik}$ is the total power adjustment of agent k; L_{ik} is the compensation price; A_{ik} and B_{ik} are bidding strategy parameters of agent k. When multiple agents participate in the auction, we can get the following equation if a uniform compensation price L_i used in the dispatching and trading centre.

$$L_i = \frac{\Delta D_{iz} + \dfrac{B_{ik}}{A_{ik}} + \displaystyle\sum_{k\neq k0}^{n} \dfrac{B_{ik}}{A_{ik}}}{\dfrac{1}{A_{ik}} + \displaystyle\sum_{k\neq k0}^{n} \dfrac{1}{A_{ik}}} = h(A_{ik}, B_{ik}) \tag{2}$$

$$\Delta D_{ik} = \frac{L_i - B_{ik}}{A_{ik}} = g(A_{ik}, B_{ik}) \tag{3}$$

Where, $A_{ik}, B_{ik}\ (k \neq k0)$ represent the bidding parameters of other agents except k_0; $\triangle D_{iZ}$ represents power adjustment amount in period i.

The bidding model of the agent k is established as follow, which takes the greatest profit as the goal.

$$\max\{Esy\} = \max\{|\ \Delta D_{ik}\ |\ L_{ik} - |\ \Delta D_{iEX}\ |\ cost_{iEX} - |\ \Delta D_{iP}\ |\ cost_{iP}\} \tag{4}$$

Here ΔD_{iP} and ΔD_{iEX} respectively represents the power adjustment amount of the price type load and the incentive type load; $cost_{iP}$ and $cost_{iEX}$ respectively donates the cost of the price type load and the incentive type load, which can be obtained by

$$cost_{iP} = -\frac{l_{i0}(1+2\Delta D_{iP})}{D_{i0P}\varepsilon_{ii}} \tag{5}$$

$$cost_{iEX} = \alpha l_{i0} \quad or \quad cost_{iEX} = (1-\beta)l_{i0} \tag{6}$$

Where, ε_{ii} represents self-elastic coefficient (the price type load with self-elastic demand is considered to simplify the calculation); l_{i0} is the initial price; D_{i0P} and D_{i0EX} respectively represents the initial power of the price type load and the incentive type load; α and β respectively represents the compensation rate and discount rate of the incentive type load. The lowest cost agent will be chosen to control the local loads. According to the formula (5) and (6), the agent can get the dispatching cost of different loads and determine the load amount to participate in dispatching.

There are a set of constraints:

$$L_{i\min} \le L_i \le L_{i\max} \tag{7}$$

$$\Delta D_{iEX\min} \le \Delta D_{iEX} \le \Delta D_{iEX\max} \tag{8}$$

$$\Delta D_{iP\min} \le \Delta D_{iP} \le \Delta D_{iP\max} \tag{9}$$

$$\Delta D_{iV} = \Delta D_{ik} + \Delta D_{iother} \tag{10}$$

Formula (7) is the quoting constraint of the load agent; Formula (8) and (9) are the constraint of power adjustment of the load in the agent; Formula (10) is the constraint of power balance. Where $\triangle D_{iV}$ is power adjustment amount that power system requires; ΔD_{iother} is power adjustment amount of other agents and generators.

In the bidding process, load agents that participate in grid dispatching cannot get the quoting information of each other. The historical quoting data of load agents is public available in Australian national electricity market. The agent can make educated guesses about the bidding strategy of other agents by learning from the historical data exposed on the dispatching and trading centre. On this basis it can further optimize the bidding parameters to get more revenue. The guessing strategy of agent k is to take the bidding behavior in the latest bidding period (t_n) at the same scene as the quoting strategy they can used in period (i), which is shown as follow.

$$A_{ik}' = A_{tnk}, \quad B_{ik}' = B_{tnk} \quad (k \neq k0) \tag{11}$$

Where the subscript tn means the latest time period with the same or similar bidding scene; A_{tnk} and B_{tnk} represent the bidding strategy of agent k in period tn.

The quoting strategies of all agents are consistent in this paper, and there is a non-cooperative game relationship between each other. When all of the agents guess others' bidding strategies, they will get the expected maximum benefits. The bidding process will achieve an acceptable Nash equilibrium status, and they will keep using this quoting strategies in the subsequent same scene. The Nash equilibrium status may not be the global optimal solution in the bidding process. In order to get the global optimum, the satisfaction degree matrix (M_{SD}) and the ε-degree search method are introduced to correct the bidding strategy (Gao Zhan et al,. 2008, Xu Min et al., 2007).

a. The matrix M_{SD}.

Define $\{y_{nk}\}$ and $\{y_{nc}\}$ are the satisfaction degree phasor of gent k and the dispatching centre, and y_{nk} and y_{nc} respectively represents satisfaction degree of agent k and the dispatching centre for the n-th bidding result at the same scene. The value of '1' means they satisfy with the results, while the value of '0' means they dissatisfy with the results.

$$y_{nk} = \begin{cases} 1 & \forall i \neq n : sy_{nk} \ge sy_{ik} \\ 0 & \exists i \neq n : sy_{nk} < sy_{ik} \end{cases} \tag{12}$$

$$y_{nc} = \begin{cases} 1 & \forall i \neq n : cost_{nc} \ge cost_{ic} \\ 0 & \exists i \neq n : cost_{nc} < cost_{ic} \end{cases} \tag{13}$$

Where sy_{nk} and sy_{ik} respectively represents the revenue of agent k in n and i period; $cost_{nc}$ and $cost_{ic}$ respectively represents the dispatching cost in time period n and i. After each bidding, the agent updates its satisfaction degree to the dispatching centre according to its current and historical revenues. Then, the dispatching centre updates the M_{SD} according to these satisfaction degree phasors and open M_{SD} as historical information before the next bidding. The expression of M_{SD} is shown as follow.

$$M_{SD} = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1k} \\ y_{21} & y_{22} & \cdots & y_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ y_{n1} & y_{n2} & \cdots & y_{nk} \end{bmatrix} \tag{14}$$

Before a new bidding process, the agents search whether there is the matrix M_{SD} with satisfaction degree phasors are '1'. If it exists, all the agents can use the strategies in the next bidding; and if there does not exist, all the agents should continue to guess the strategies of others and optimize their own bidding parameters.

b. ε-degree searching strategy.

To prevent the bidding process converge to a local optimal solution, the ε-degree searching strategy is introduced to the bidding strategy of the agent. It means that some new bidding parameters other than the normal selected strategy will be selected with a small probability ε. The small probability ε is defined as $1/n_{jy}$, and n_{jy} is bidding times at the same scene. The flowchart of the bidding strategy of the load agent is shown as Fig. 2.

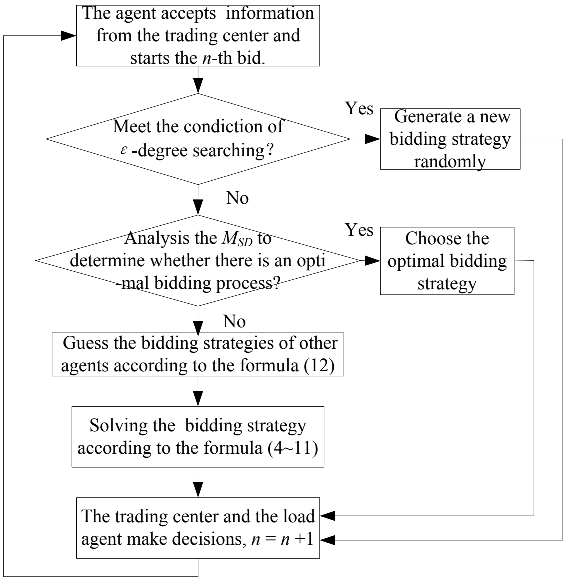

Fig. 2 The flowchart of the bidding strategy of the load agent

3.2 dispatch centre scheduling decision model

After getting the bidding information of load agents, the objective function can be built on the basis of minimal dispatching cost (excluding labor costs and losses):

$$\min\{c_{total}\} = \min\{\sum_{j=1}^{m} cost_G(\Delta D_{iGj}) + \sum_{k=1}^{n} cost_A(\Delta D_{iAk})\} \quad (15)$$

Where $cost_A(\varDelta D_{iAk})$ and $cost_G(\varDelta D_{iGj})$ respectively represents the dispatching cost of load agent k and generator j in the time period i, and the power adjustment is respectively $\varDelta D_{iAk}$ and $\varDelta D_{iGj}$.It is assumed that the generators provide a service to deal with energy imbalance by signing a contract, and the contract content includes the relationship between the power adjustment and the compensation price, as well as the power adjustment limits in each time period, etc. The relationship between the power adjustment and the compensation price of generator j is expressed as

$$L_{iGj} = A_{Gj}\Delta D_{iGj} + B_{Gj} \quad (16)$$

Where A_{Gj} and B_{Gj} represent the cost parameters of generator j. The dispatching cost for power adjustment by using the generator j can be expressed as follow.

$$cost_G(\Delta D_{iGj}) = A_{Gj}\Delta D_{iGj}{}^2 + B_{Gj}\Delta D_{iGj} \quad (17)$$

The dispatching cost for the load agent k can be expressed as follows (Ai Xin et al., 2011).

$$cost_A(\Delta D_{iAk}) = \Delta D_{iAk} L_{ik} = A_{ik}\Delta D_{ik}^2 + B_{ik}\Delta D_{ik} \quad (18)$$

The constraints include follows:

$$P_r\{|D_{iG0} + D_w - D_{load0} - \Delta D_{iV}| \le \Delta D\} \ge \lambda_0 \quad (19)$$

$$\Delta D_{iV} = \sum_{k=1}^{n} \Delta D_{iAk} + \sum_{j=1}^{m} \Delta D_{iGj} \quad (20)$$

$$\Delta D_{iAk\min} \le \Delta D_{iAk} \le \Delta D_{iAk\max} \quad (21)$$

$$L_{iAk} = L_{iGj} \quad (k=1\sim n, j=1\sim m) \quad (22)$$

Formula (19) and (20) are power balance constraints. The confidence of the imbalanced power in the interval [-$\varDelta D$,$\varDelta D$] is no less than λ_0, when considering the probability distribution of the wind power output; Formula (21) is the constraints of the power adjustment of agent k, where $\triangle D_{iAkmin}$ and $\triangle D_{iAkmax}$ are the limits of the power adjustment of agent k; Formula (22) is the bidding constraints, which means that the trading centre deals with all of the load agents and generators with a same compensation price. In addition, there are some constraints of the power grid and generators described in many researches such as the upper and lower limits, climbing rate, reserve capacity of conventional generators.

4 THE DISPATCHING AND TRADING PROCESS BASED ON LOAD AGENTS

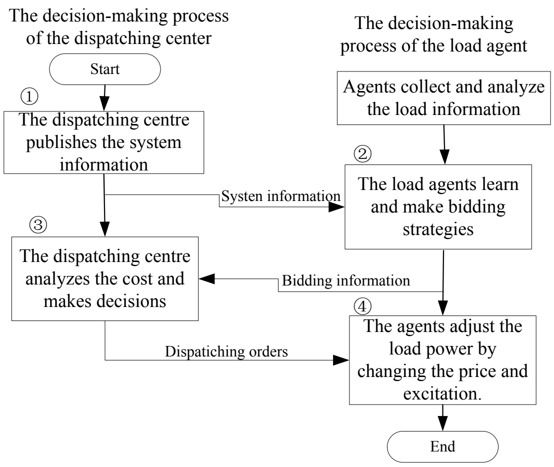

Fig. 3 The flowchart of dispatching and trading process

Based on the dispatching architecture with multi-agent technology, the dispatching and trading process can be divided into four steps: the dispatching and trading centre releases information, the load agents learn and make bidding strategies, the dispatching and trading centre analyses the cost and makes decision, the load agents make decision and adjust the load power by changing the price and excitation. The specific dispatching and trading process is shown as follow.

5 SIMULATIONS

Take IEEE 39-node system as test example, the original load data and regional wind power data are used to simulate the load dispatching model. Two generator nodes are selected to access wind farms. There are two load agents for the system loads, and each agent contains the price type load, the incentive type load and the constant type load. The concrete parameters are shown in Table 1.

Table 1 Parameters of load agents

		Agent1	Agent2
the price type load	Proportion	20%	15%
	elastic coefficient	-1.2	-1.3
the incentive type load	Proportion	20%	25%
	compensation rate	1.1	1.2
	discount rate	0.8	0.9
the constant type load	Proportion	60%	60%

Suppose that the wind power output predicted 15min earlier is normal distribution $N(PP(t),\sigma^2)$, and the standard deviation is 50MW. The prediction curves of load and wind power are shown in Fig. 4

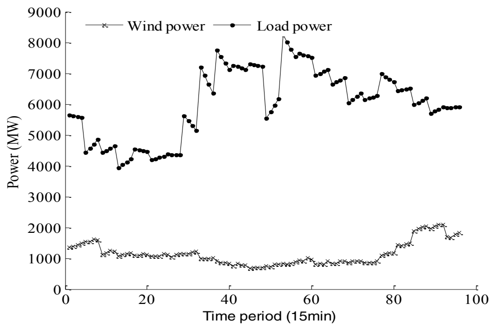

Fig. 4 System parameters

Simulation Case 1: There are two simulation conditions, only the generators are involved in dispatching and the load agents participate in dispatching. The confidence level of imbalanced power in the interval [-100MW, 100MW] is no less than 95%. After the system run 24 hours, the dispatching cost, load agent profits, and power adjustment are shown below.

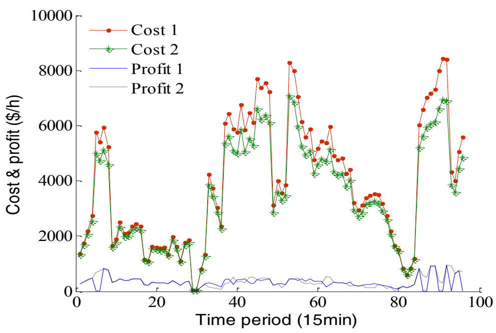

Fig. 5 Dispatching cost and agents' profits

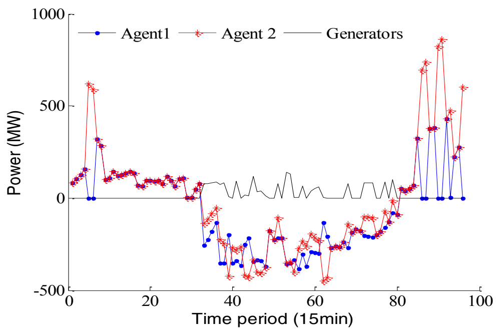

Fig. 6 Power distribution between the agents and generators

In Fig. 5, the Cost 1 and Cost 2 respectively means the cost of the dispatching centre when the load agents participate in the dispatching and not, the Profit 1 and Profit 2 respectively means the profit of the agent 1 and agent 2; In Fig. 6, the curve of Agent 1, Agent 2 and Generators respectively means the power adjustment of the agent 1, agent 2 and the generators. The simulation results show that the dispatching cost reduces obviously when load agents participate in system, and the load agents could get some profits. In addition, most of the power adjustment is provided by the load agents, which will greatly reduce the reserve capacity of the system.

Simulation Case 2: When the load agents participate in dispatching, simulations are carried out under the following two conditions. The condition 1 keeps the same with simulation case 1; in the condition 2, the uncertainty of wind power is ignored and the power balance constraint is changed to a deterministic constraint. The dispatching cost and the imbalanced power consumption under the two conditions are shown as follows.

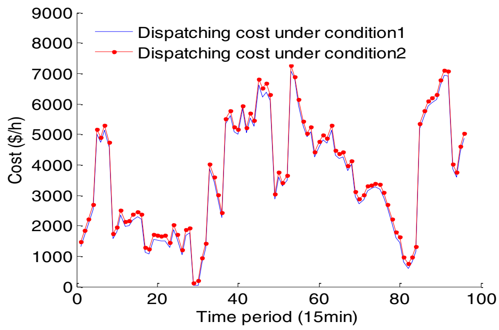

Fig. 7 Dispatching cost in the two simulation conditions

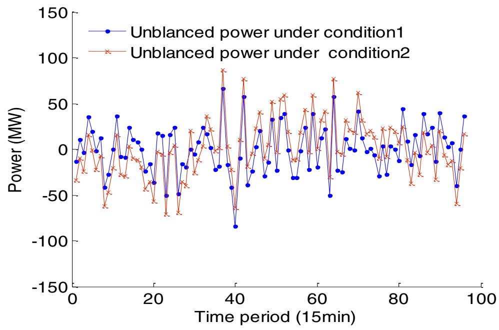

Fig. 8 Elimination of the imbalanced power

As shown in Fig. 7 and Fig. 8, there are similar effects on imbalanced power consumption under two conditions, but the dispatching cost under condition 1 is lower.

Simulation Case 3: To prove the effect of the bidding strategy proposed in this paper, the simulations under the following two conditions are carried out with power adjustment of +1550MW. The dispatching process is simulated for 300 times when the bidding strategy proposed in this paper is adopted. The cost and profit results in these simulations are shown as follow.

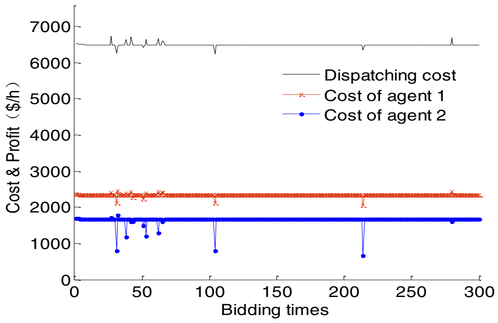

Fig. 9 Bidding results

As shown in Fig. 9, when the bidding strategy proposed in this paper is adopted, the dispatching cost and the agents' profits tend to an optimum level with the bidding times increasing. In addition, some new strategies with a small probability ε are adopted. It keeps the cost of dispatching centre and the profit of load agents at an optimum level with a larger probability.

6 CONCLUSIONS

Based on multi-agent technology, the architecture, mechanism, mode and strategy of load dispatching are studied in this paper. And then, simulation examples are carried out to verify the effectivity of these model and strategies. The following conclusions can be obtained: (1) With the mechanism proposed in this paper, the economy of dispatching system can be improved by fully utilizing different types of demand-side resources; (2) Considering the uncertainty of wind power as a chance constraint, the dispatching strategy is helpful to reduce the dispatching cost of the system; (3) With the satisfaction degree matrix and the ε-degree search method, the bidding strategies have contributed to a global optimum result for the bidding direction and keep the cost of dispatching centre and the profit of load agents remain at optimum levels with a larger probability. It is important to note that the satisfaction degree matrix can be formed by low-carbon, network losses and other indicators besides the dispatching cost to lead the bidding process toward the direction we need. In addition, the demand resources cannot response to the order with a probability of 100%, and how to consider the uncertainty of demand response in the load dispatching is still need a further study.

7 ACKNOWLEDGEMENTS

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