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Decentralized P2P power trading mechanism for dynamic multi-energy microgrid groups based on priority matching

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Abstract

In order to promote the interaction among interconnected microgrids (MGs) with multiply distributed energy resources (DERs) to local energy utilization, a decentralized peer-to-peer (P2P) power trading mechanism based on priority matching is proposed. The priority indices are calculated based on scheduling results and quotations by an independent MG operator (IMO), which protect effectively the privacy and represent the bargaining willingness of MGs. According to the supply–demand ratio within a matching pair, each MG is permitted to update its quotation multi-times until the convergence or updated number limitation is reached. The clearing price of each pair is calculated by the mid-market rate (MMR) method. Because the imbalanced power is different with the autonomous scheduling in a MG at different dispatching time, the different power requirements of MGs results in the formation of the dynamic MG groups. The simulation results in an interconnected multi-microgrid system (IMMGS) with 4 MGs show the proposed decentralized P2P mechanism is reasonable and effective.

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Keywords: IMMGS; Priority indices; Peer-to-peer trading; Dynamic microgrid; Trading mechanism; Multiple scenarios

1. Introduction

The multi-energy complementary MG equipped with wind turbine (WT), photovoltaic (PV), micro-turbine (MT), energy storage (ES), gas boiler (GB), electric conditioner (EC) and other DERs possesses more flexible resources to maintain the balance between supply and demand. However, the differences of various energy demands and the coupling relationships among the multi-energy flows limit the adjustability of the MG. With the continuous development of MGs, the adjacent MGs can be connected to form an IMMGS, which can reduce the cost and improve the local consumption of new energy [1]. Meanwhile, the power fluctuation and intermittency of renewable energy of the grid IMMGS may decrease its security so that the IMMGS is difficult to be maintained. Therefore, the good trading mechanism design is necessary to guarantee the security and reliability [2].

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Each MG as a prosumer plays a role in production or consumption of energy at some time [3]. In order to obtain more benefits or reduce the energy cost, a MG needs sell/buy the imbalanced power to/from other community members in IMMGS in a transactive market, where it can independently determine the trading parameters such as objective, time, quantity and price, etc. The P2P power sharing based on the concept of computer transition network has provided such a platform [4].

The P2P energy market was divided into three categories: coordinated market, community market and decentralized market [5]. In the coordinated and community market [6], the distribution system operator (DSO) which collects the information from all the MGs optimizes the dispatching of DERs to effectively reduce the operating cost. However, with the increasing number of MGs, the computational burden and privacy cannot be guaranteed [7]. Thus, the decentralized P2P trading which suits for IMMGS with large number of MGs has been studied. A novel algorithm using primal–dual gradient method with less exchange information was proposed to clear the market in [8]. A "multi-bilateral economic dispatch" (MBED) formulation and a "relaxed consensus + innovation" (RCI) approach were proposed to construct a fully decentralized P2P market in [9]. Nevertheless, the key information is still accessible to other participants. A new trading mechanism should be designed for privacy preservation of transactions.

In terms of pricing in a P2P energy trading, a common manner is the continuous double auction (CDA) mechanism, in which the matching rule is obeyed based on the priority of announced price without quantity [10]. However, the price is not the only concern in reality. To deal with the pricing imperfection of CDA, the MMR pricing method based on independent quotation and bidding quantity is adopted to represent both the real willingness and fairness of all participants.

Given the context, this paper proposes an improved double auction mechanism based on priority matching for P2P energy trading, which ensures privacy of bidding information and provides faster convergence in auction processes. The main contributions of this paper are summarized as follows:

(1) An improved bidding mechanism for decentralized P2P energy trading based on the rapid multiple matching of the priority indices between buyers and sellers is proposed so that the efficiency of the trading process is improved.

(2) The priority indices designed for both the buyer and the seller protect the privacy of each participating MG. Meanwhile, the calculation of the priority indices is simple and quick.

(3) The dynamic MG groups formed after each trading show the participating willingness of all prosumers, improve the flexibility of transactions, and favor local energy balance.

The remaining of this paper is organized as follows. The decentralized P2P trading mechanism is introduced in Section 2. Priority indices model is introduced in Section 3. And Section 4 establishes the optimal scheduling model of a MG. Section 5 introduces the P2P trading models including the quotation update model and clearing price model. Case studies are conducted in Section 6 to prove the validity of the proposed model. Section 7 gives the final conclusion.

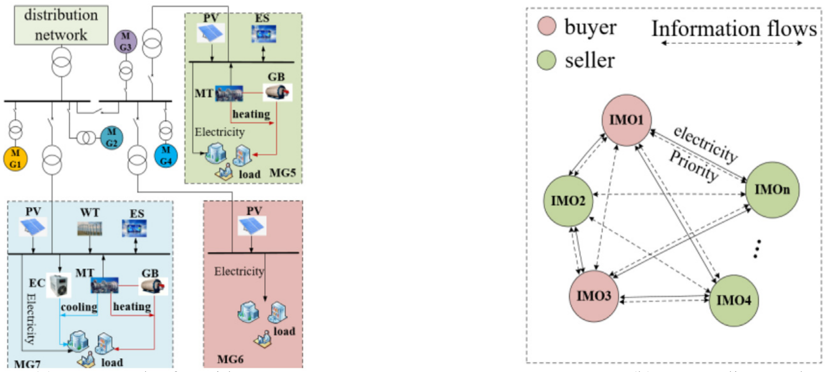
2. The decentralized P2P trading mechanism

2.1. Framework of the IMMGS

The framework of IMMGS and the internal structure of MGs are shown in Fig. 1(a), where an IMO conducts the energy economic management to balance energy generation and consumption within a MG. When the generation cannot be equivalent to consumption in a MG, its IMO would participate the P2P trading market without a third party, which is shown in Fig. 1(b). The heating and cooling energy are balanced within each MG, while only the electricity trading among MGs is considered in this work.

2.2. Decentralized P2P trading mechanism

Combined auction-based mechanism [11] and bilateral contract-based [12] one, a novel decentralized P2P trading mechanism based on matching the priority indices of buyers and sellers which will be presented in Section 3 is proposed in this work. Following the ordering rule, buyer and seller indices are all sorted in a descending order, thus the buyer and the seller with same order form a winning buyer–seller pair. Every pair in the matching process checks the actual bid/ask prices and quantities each other. The MGs with manipulated information will be prohibited from participating in the P2P transactions. All MGs with power surplus or shortage update their bid/ask prices and



(a)Framework of a grid IMMGS. (b) P2P trading market.

Fig. 1. The framework of a grid IMMGS and the P2P trading market.

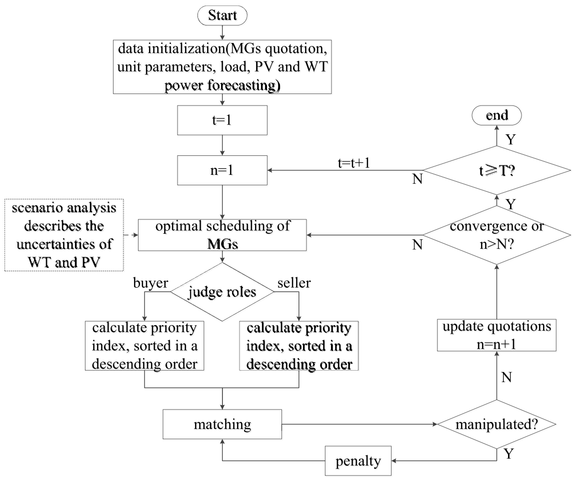


Fig. 2. The P2P trading process.

quantities and resubmit new indices until reaching convergence or maximum trading rounds. The clearing price of each pair is calculated by the MMR. The P2P trading process is shown in Fig. 2. At each trading time t, the power supply or demand of each MG changed with its autonomous dispatching scheme results in different matching requirements, and thus dynamic MG groups are formed.

3. Priority indices model

In P2P transaction, each MG hopes to match with the prosumer who has suitable electricity quantity and price. Considering the privacy preservation of participants, we propose a buyer priority index and a seller priority index based on their expected prices and power shown as Eqs. (1) and (2), respectively.

$$w_{i,t}^{\text{buy}} = -\left(\frac{P_{i,t}^{\text{buy}}}{P_t^{\text{ex,max}}} + \frac{c_{i,t}^{\text{buy}}}{c_t^{\text{buy,grid}}}\right) \tag{1}$$

$$w_{j,t}^{\text{sell}} = \frac{P_{j,t}^{\text{sell}}}{P_t^{\text{ex,max}}} + \frac{c_t^{\text{sell,grid}}}{c_{j,t}^{\text{sell}}} \tag{2}$$

where $w_{i,t}^{\text{buy}}$ and $w_{j,t}^{\text{sell}}$ are the priority indices of buyer i and seller j at time t, respectively. $P_{i,t}^{\text{buy}}$ and $P_{j,t}^{\text{sell}}$ denote the quantity demanded by buyer i and quantity supplied by seller j at time t, respectively. $P_t^{\text{ex,max}}$ is the maximum trading quantity allowed in the P2P market at time t. $c_{i,t}^{\text{buy}}$ and $c_{j,t}^{\text{sell}}$ denote the bid price and the ask price at time t, respectively. $c_t^{\text{buy,grid}}$ and $c_t^{\text{sell,grid}}$ are prices exchange with grid at time t, respectively.

4. Optimal scheduling model of a MG

An IMO conducts optimal scheduling within the MG for each round transaction with K matching, and then submits the quantity demanded/supplied at each trading time to the day-ahead P2P market. The scheduling model of a MG is taken the operational costs minimization as the objective. In the model, the scenario analysis method is utilized to deal with the uncertainty of WT and PV power. The scenario generation and scenario reduction are executed by the LHS method and synchronous back substitution elimination method, assuming that WT and PV power prediction error follows $N(0, \delta^2)$ normal distribution.

4.1. Objective function

The objective function is to minimize the maintenance cost and the interaction cost with other prosumers, which is shown as (3).

$$\min C^{\text{total}} = \sum_{t=1}^{T} \left(\sum_{s=1}^{N^S} \xi_s (\mathrm{K}_{\text{pv}}^{\text{w}} P_t^{\text{PV}} + \mathrm{K}_{\text{wt}}^{\text{w}} P_t^{\text{WT}} + \mathrm{K}_{\text{es}}^{\text{w}} P_{t,s}^{\text{ES}} + \mathrm{K}_{\text{mt}}^{\text{w}} P_{t,s}^{\text{MT}} + \mathrm{K}_{\text{gb}}^{\text{w}} P_{t,s}^{\text{GB}} + \mathrm{K}_{\text{c}}^{\text{w}} P_{t,s}^{\text{EC}} + c_{K,n,t}^{\text{buy}} P_{t,s}^{\text{buy}} - c_{K,n,t}^{\text{sell}} P_{t,s}^{\text{sell}}) \right) \tag{3}$$

where C^{total} is the total cost of a MG in one day. N^{S} is the number of scenarios.ξ_s is probability of scenario s. $\mathrm{K}_{\text{pv}}^{\text{w}}$, $\mathrm{K}_{\text{wt}}^{\text{w}}$, $\mathrm{K}_{\text{es}}^{\text{w}}$, $\mathrm{K}_{\text{mt}}^{\text{w}}$, $\mathrm{K}_{\text{gb}}^{\text{w}}$, $\mathrm{K}_{\text{c}}^{\text{w}}$ are maintenance coefficient of PV, WT, ES, MT, GB and EC, respectively; $P_{t,s}^{\text{PV}}$, $P_{t,s}^{\text{WT}}$, $P_{t,s}^{\text{ES}}$, $P_{t,s}^{\text{MT}}$, $P_{t,s}^{\text{GB}}$, $P_{t,s}^{\text{EC}}$ are PV power, WT power, ES power, MT power, GB power and EC power of scenario s at time t, respectively. $c_{K,n,t}^{\text{buy}}$ and $c_{K,n,t}^{\text{sell}}$ are bid and ask prices for a MG from and to other prosumers of the Kth matching in nth round transaction at time t. $P_{t,s}^{\text{buy}}$ and $P_{t,s}^{\text{sell}}$ represent purchasing and selling power from and to other prosumers for a MG in scenario s at time t.

4.2. Constraints

(1) power balance constraints

The power supply and demand in a MG must be balanced at any time. The balance constraints of power including the cooling power Q_t^{cool}, heating power Q_t^{heat} and electric power P_t^{load} are shown as (4), (5) and (6), respectively.

$$Q_{t,s}^{\text{MT,c}} + P_{t,s}^{\text{EC}} = Q_t^{\text{cool}} \tag{4}$$

$$Q_{t,s}^{\text{MT,h}} + P_{t,s}^{\text{GB}} = Q_t^{\text{heat}} \tag{5}$$

$$P_{t,s}^{\text{PV}} + P_{t,s}^{\text{WT}} + P_{t,s}^{\text{ES}} + P_{t,s}^{\text{MT}} = P_t^{\text{load}} + P_{t,s}^{\text{sell}} - P_{t,s}^{\text{buy}} \tag{6}$$

where $Q_{t,s}^{\text{MT,c}}$ and $Q_{t,s}^{\text{MT,h}}$ are the cooling and heating capacity of MT in scenario s at time t.

(2) controllable unit output constraints

$$P^{\text{MT/GB/EC,min}} \leq P_{t,s}^{\text{MT/GB/EC}} \leq P^{\text{MT/GB/EC,max}} \tag{7}$$

where $P^{\text{MT/GB/EC,min}}$ and $P^{\text{MT/GB/EC,max}}$ are the minimum and maximum power of MT, GB or EC.

(3) interactive power constraints

$$0 \leq P_{t,s}^{\text{buy}} \leq X_{t,s} P^{\text{ex,max}} \tag{8}$$

$$0 \leq P_{t,s}^{\text{sell}} \leq Y_{t,s} P^{\text{ex,max}} \tag{9}$$

$$X_{t,s} + Y_{t,s} \leq 1 \tag{10}$$

$$X_{t,s}, Y_{t,s} \in \{0, 1\} \tag{11}$$

where $P_i^{\text{ex,max}}$ is the maximum interactive power. $X_{t,s}$ and $Y_{t,s}$ are the 0–1 variables, which ensures that a MG is only a buyer/seller in scenario s at time t.

(4) ES constraints

The capacity of ES at time t is related to the capacity at time t-1. The charge and discharge power and capacity of ES must be within limitations. Meanwhile ES cannot charge and discharge simultaneously.

$$E_{t,s} = (1 - \mu_{\text{ES}})E_{t-1,s} + P_{t,s}^{\text{ch}}\eta_{\text{ch}} - P_{t,s}^{\text{dis}}/\eta_{\text{dis}} \tag{12}$$

$$E^{\min} \leq E_{t,s} \leq E^{\max} \tag{13}$$

$$0 \leq P_{t,s}^{\text{ch}} \leq X'_{t,s}P^{\text{ch,max}} \tag{14}$$

$$0 \leq P_{t,s}^{\text{dis}} \leq Y'_{t,s}P^{\text{dis,max}} \tag{15}$$

$$X'_{t,s} + Y'_{t,s} \leq 1 \tag{16}$$

$$X'_{t,s}, Y'_{t,s} \in \{0, 1\} \tag{17}$$

$$E_s(T) = E_s(0) \tag{18}$$

where $E_{t,s}$ and $E_{t-1,s}$ are the total capacity of ES in scenario s at time t and t-1. $P_{t,s}^{\text{ch}}$ and $P_{t,s}^{\text{dis}}$ are the charging and discharging power of ES in scenario s at time t. η_{ch} and η_{dis} are charge and discharge coefficients. μ_{ES} is the self-discharge coefficient. $E^{\min}$ and $E^{\max}$ are the upper and lower capacity limits of ES. $P^{\text{ch,max}}$ and $P^{\text{dis,max}}$ are the maximum charge and discharge power. $X'_{t,s}$ and $Y'_{t,s}$ are the 0–1 variables, which represents the state of ES in scenario s at time t.

5. P2P trading models

In a P2P trading at time t, the required quantity of a MG may be satisfied by K matching. It submits its price of the kth ($k > 1$, $k \in K$) matching of the nth ($n \in N$) trading round based on the supply–demand ratio of the (k-1)th matching of the nth trading round, and the price of the 1st matching of the nth trading round is got by the supply–demand ratio of the Kth matching of the ($n-1$)th trading round. Thus the quotation can indicate the relationship between power supply and demand, as well as guide the local power balance.

5.1. Updated bid/ask price model

In the multiple auctions, a buyer and a seller of each pair are both permitted to update its index based on the supply–demand ratio of the last matching. The supply–demand ratio of the mth pair of the nth trading round at time $tR_{m,n,t}$ is expressed by

$$R_{m,n,t} = \frac{P_{m,n,t}^{\text{sell}}}{P_{m,n,t}^{\text{buy}}} \tag{19}$$

$$X_{m,n,t} = \frac{1}{R_{m,n,t}} \tag{20}$$

where $P_{m,n,t}^{\text{sell}}$ and $P_{m,n,t}^{\text{buy}}$ are the seller's supply quantity and the buyer's demand quantity in the mth pair of the nth trading round at time t;.$X_{m,n,t}$ is the reciprocal of $R_{m,n,t}$.

Supposed that a MG through the kth matching be a member of the mth pair of the nth trading round, and it can be divided into two situations according to $R_{m,n,t}$.

(a) $0 < R_{m,n,t} \leq 1$

When $0 < R_{m,n,t} \leq 1$, Eq. (21) describes how to calculate ask price of the (k+1)th matching of the nth round trading at time $tc_{k+1,n,t}^{\text{sell}}$ for a seller [13].

$$c_{k+1,n,t}^{\text{sell}} = \frac{1}{\mathrm{a}R_{m,n,t} + \mathrm{b}}, \mathrm{a} > 0 \tag{21}$$

where a, b are the constants.

$R_{m,n,t} = 1$ indicates that the demand is equal to supply, the seller's ask price is updated by the average value of ask and bid prices.

$$c_{k+1,n,t}^{\text{sell}} = (c_{k,n,t}^{\text{buy}} + c_{k,n,t}^{\text{sell}})/2 = \frac{1}{\mathrm{a} + \mathrm{b}} \tag{22}$$

Supposed $R_{m,n,t} \to 0$, it indicates that there are almost no electricity supplies, the buyer must purchase from other prosumers, the seller's ask price is updated by the buyer's bid price.

$$c_{k+1,n,t}^{\text{sell}} = c_{k,n,t}^{\text{buy}} = \frac{1}{\text{b}} \tag{23}$$

The constants a and b can be obtained by substituting (22) and (23) to (21), the seller's ask price is updated by (24).

$$c_{k+1,n,t}^{\text{sell}} = \frac{c_{k,n,t}^{\text{buy}}(c_{k,n,t}^{\text{buy}} + c_{k,n,t}^{\text{sell}})}{c_{k,n,t}^{\text{buy}}(1 + R_{m,n,t}) + c_{k,n,t}^{\text{sell}}(1 - R_{m,n,t})} \tag{24}$$

Meanwhile the buyer hopes to improve its matching order by satisfying the following equation.

$$P_{m,n,t}^{\text{buy}} c_{k+1,n,t}^{\text{buy}} = P_{m,n,t}^{\text{sell}} c_{k,n,t}^{\text{sell}} + (P_{m,n,t}^{\text{buy}} - P_{m,n,t}^{\text{sell}}) c_{k,n,t}^{\text{buy}} \tag{25}$$

So the buyer's bid price is updated by (26).

$$c_{k+1,n,t}^{\text{buy}} = c_{k,n,t}^{\text{sell}} R_{m,n,t} + c_{k,n,t}^{\text{buy}}(1 - R_{m,n,t}) \tag{26}$$

(b) $R_{m,n,t} \geq 1$ $(0 < X_{m,n,t} \leq 1)$

When $0 < X_{m,n,t} \leq 1$, Eq. (27) describes how to calculate bid price of the (*k*+1)th matching of the *n*th round at time *t* $c_{k+1,n,t}^{\text{buy}}$ for a buyer.

$$c_{k+1,n,t}^{\text{buy}} = \frac{1}{\text{c}X_{m,n,t} + \text{d}}, \text{c} > 0 \tag{27}$$

where c, d are the constants.

Using the same analyzation, the buyer's bid price and the seller's ask price are updated by (28) (29).

$$c_{k+1,n,t}^{\text{buy}} = \frac{c_{k,n,t}^{\text{sell}}(c_{k,n,t}^{\text{buy}} + c_{k,n,t}^{\text{sell}})}{c_{k,n,t}^{\text{sell}}(1 + X_{m,n,t}) + c_{k,n,t}^{\text{buy}}(1 - X_{m,n,t})} \tag{28}$$

$$c_{k+1,n,t}^{\text{sell}} = c_{k,n,t}^{\text{buy}} X_{m,n,t} + (1 - X_{m,n,t}) c_{k,n,t}^{\text{sell}} \tag{29}$$

5.2. Transaction pricing model

At each trading time *t*, each pair of transaction has been cleared after *N* trading rounds. The MMR method is utilized to calculate the clearing price. Firstly, the average value of the two quotations of a pair is expressed by

$$c_{m,t}^{\text{mean}} = \frac{c_{k,N,t}^{\text{buy}} + c_{k,N,t}^{\text{sell}}}{2} \tag{30}$$

where $c_{m,t}^{\text{mean}}$ is the mean price of the *m*th pair at time *t*.

Considering the supply and demand of the *m*th pair, the calculation of clearing price of *m*th pair at time *t* $c_{m,t}^{\text{clr}}$ can be divided into the following three cases:

(1) When the seller supply is more than the buyer demand, the clearing price should incline to the buyer's bid price.

$$c_{m,t}^{\text{clr}} = \frac{P_{k,N,t}^{\text{buy}} c_{m,t}^{\text{mean}} + (P_{k,N,t}^{\text{sell}} - P_{k,N,t}^{\text{buy}}) \min\{c_{k,N,t}^{\text{buy}}, c_{k,N,t}^{\text{sell}}\}}{P_{k,N,t}^{\text{sell}}} \tag{31}$$

(2) When the seller supply is less than the buyer demand, the clearing price should incline to the seller's ask price.

$$c_{m,t}^{\text{clr}} = \frac{P_{k,N,t}^{\text{sell}} c_{m,t}^{\text{mean}} + (P_{k,N,t}^{\text{buy}} - P_{k,N,t}^{\text{sell}}) \max\{c_{k,N,t}^{\text{buy}}, c_{k,N,t}^{\text{sell}}\}}{P_{k,N,t}^{\text{buy}}} \tag{32}$$

(3) When the seller supply equals to the buyer demand, the clearing price is the mean value of both quotations.

$$c_{m,t}^{\text{clr}} = c_{m,t}^{\text{mean}} \tag{33}$$

The clearing prices for matching pairs got by the above models can reflect effectively the relationship between supply and demand.

6. Example analysis and comparison

6.1. Case overview

An IMMGS with 4 MGs is utilized to demonstrate the proposed mechanism. The MG1 includes PV, ES, MT, GB, EC, electric, heating, and cooling load. The MG2 includes PV, WT, EC, electric and cooling load. The MG3 is composed of PV, WT, ES, GB, electric and heating load. The MG4 is composed of PV and electric load. The maximum power of MT, GB and EC is 500 kW. For ES, the minimum capacity is 100 kW, the initial capacity is 20% of the total capacity, the maximum charge and discharge power is 100 kW, and the charge and discharge efficiencies are both 0.9 u. The valley period of grid is 0:00∼6:00, and purchase price is 0.12 yuan/kWh and sale price is 0.03 yuan/kWh. The normal periods include 7:00∼10:00,16:00∼17:00 and 21:00∼23:00, the purchase and sale prices are 0.48 yuan/kWh and 0.31 yuan/kWh, respectively. The peak periods include 11:00∼13:00 and 18:00∼20:00, the purchase and sale prices are 0.87/kWh and 0.61 yuan/kWh, respectively. The electric, heating and cooling load prediction of each MG are shown in Fig. 3∼Fig. 4.

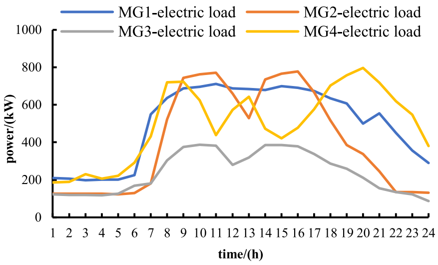


Fig. 3. Electric load.

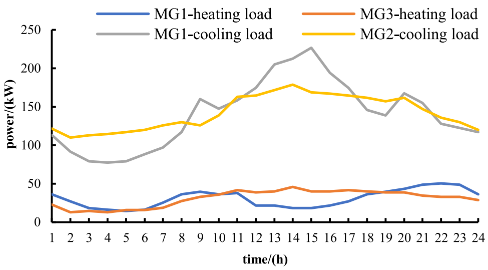


Fig. 4. Heating and cooling load.

We compare the results in three cases: the uniform price [13] in case A, the supply and demand allocated proportionally [14] in case B, and the proposed priority matching in this paper in case C. The trading round is set 10.

6.2. Optimal results

• scheduling results

Taking WT power of MG2 as an example, the results of scenario generation and reduction are shown in Fig. 5, where the sampling size is 1000, scenario threshold is 10.

The probability of each scenario occurring is shown in Table 1.

Table 1. Probability of each scenario.

Scenarios	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Probabilities	0.052	0.121	0.074	0.1	0.047	0.178	0.091	0.077	0.15	0.11

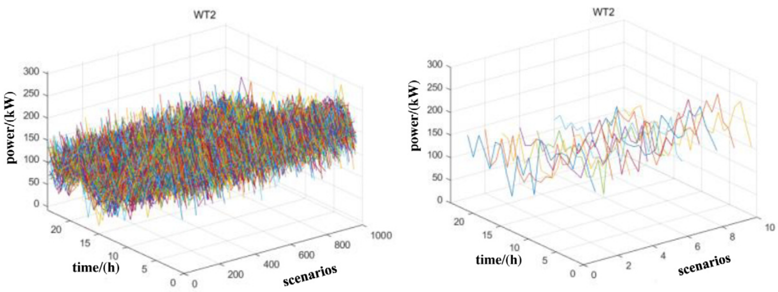


Fig. 5. Results of scenario generation and reduction.

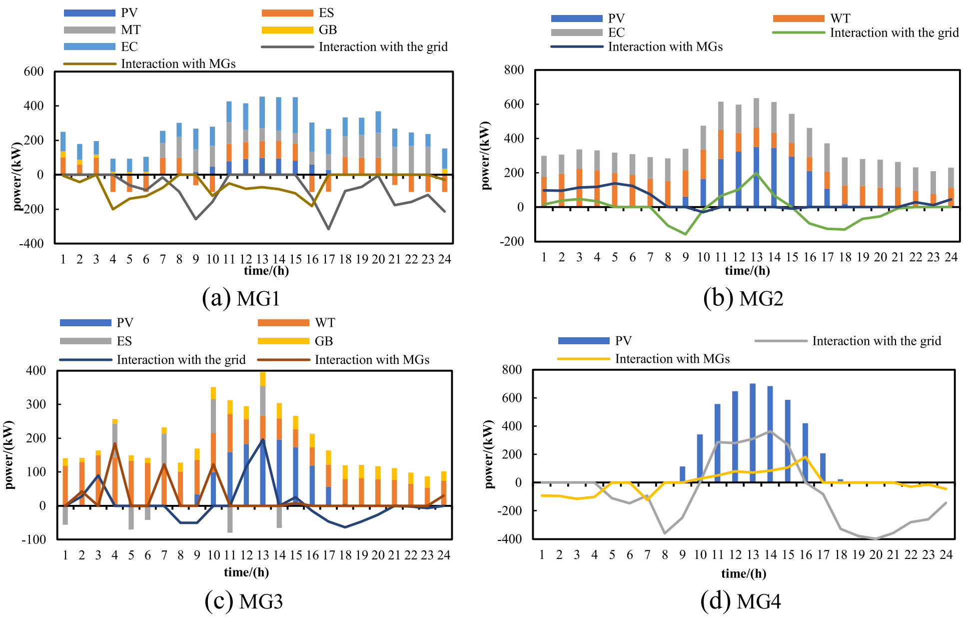


Fig. 6. Autonomous scheduling result of each MG.

Take S6 with maximum probability as an example, the scheduling results of each MG are shown in Fig. 6. ES power is positive for discharging and negative for charging. The MG1 with high PV generation and large load is a buyer as shown in Fig. 6(a). ES charges at low price (e.g. 4:00∼6:00) and discharges at peak price (e.g. 11:00∼15:00) to reduce the cost. MG2 may be a buyer or a seller at some time as shown in Fig. 6(b), which is determined by the cooling load supplied by EC. The ES discharges when the power demand of MG3 is large, and it charges when the PV output is great as shown in Fig. 6(c). Due to the single generation equipment, MG4 is a seller or a buyer at some time determined by PV output as shown in Fig. 6(d).

The interactive power with the grid in three cases is shown in Table 2. Compared with no coordination, the interactive power decreases considerably through coordination. The interactive power in case C is comparative with that in case B, which verifies the effectiveness of the proposed mechanism. Moreover, the privacy of each MG is protected in case C because case A and case B require disclosure of specific quantity and price information.

Table 2. Interactive power with the grid in three cases.

Cases	Case A	Case B	Case C
Buying electricity (kW)	8188.8	6221.24	6220.9
Selling electricity (kW)	4501.6	2554.03	2533.7

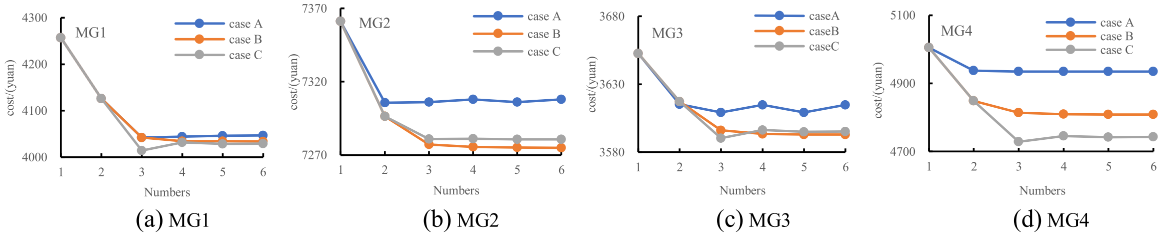


Fig. 7. Cost convergency of four MGs in three cases.

• cost results

The cost of each MG varies with the trading rounds in three cases as shown in Fig. 7. It can be seen that the P2P trading is converge after about 5 rounds of transactions in case B and case C, while the vibration occurs in MG2 and MG3 in case A. Compared with case A, the cost of each MG reduces in case B and case C.

6.3. Trading process

Take $t = 4:00$ as an example to illustrate the trading process. The trading parameters of all MGs at trading round 1 and 2 are as shown in Table 3. There is only power supply in the market after the 1th matching at the 1th trading round, when the 1th trading round is finished. In the 2th trading round, there are still supply and demand after the 1th matching, therefore they would update their priority indicators for the 2th matching.

The updated price processes of four MGs in trading rounds are shown in Fig. 8.

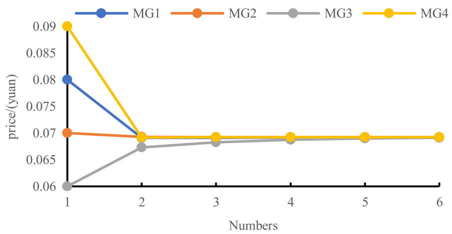


Fig. 8. Updated price at t=4:00.

Table 3. Trading parameters in 2 trading rounds.

n	MG(role)	Price(yuan)	Quantity(kW)	Priority	kth matching objects
1	MG1(buyer)	0.08	0.69	−0.6680	MG2
	MG2(seller)	0.07	152.84	0.7342	MG1
	MG3(seller)	0.06	184.36	0.8687	MG4
	MG4(buyer)	0.09	102.67	−0.9553	MG3
2	MG1(buyer)	0.07→0.0691	200.69→15.64	−0.9847→−0.6071	MG3, MG2
	MG2(seller)	0.07→0.0693	152.84→50.17	0.7343→0.5332	MG4, MG1
	MG3(seller)	0.0673	184.36→0	0.8361	MG1
	MG4(buyer)	0.0691	102.67→0	−0.7680	MG2

Finally, MG1 buys power from MG2 and MG3 at 0.0692 yuan/kW and 0.0691 yuan/kW, respectively, MG2 sells to MG4 at 0.0692 yuan/kW, and then MG2 sells power to the distribution network according to the feed-in tariff.

7. Conclusions

In this paper, the forming method of dynamic MG groups which is guided by priority indices matching is proposed. Through the simulation verification of examples, the main conclusions can be summarized as follows:

(1) The proposed priority model can increase the trading flexibility effectively and protect privacy of players fully.

(2) The proposed P2P trading mechanism can achieve convergence faster and promote local balance.

(3) The interaction power with the distribution network has been reduced, which improves the safety and stability of the grid.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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