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RESEARCH ON ENERGY MANAGEMENT STRATEGY OF REGIONAL ENERGY STATION BASED ON COORDINATED DOUBLE AUCTION MARKET

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ABSTRACT
As the core component of the energy coupling link of integrated energy system, the regional energy station undertakes important tasks such as energy allocation and controlling, so it's imperative to study the energy management strategy of it. This paper proposes a double auction based energy management strategy of the energy station. The energy station model and load bidding model are explored. The electricity-heat coordinated market model is constructed to achieve the coordinated clearing of electricity and heat, optimizing the resource allocation. The case study demonstrates that the proposed method can optimize energy production and usage, saving energy cost for energy station and users.

Keywords: energy management strategy, regional energy station, double auction, market clearing

1. INTRODUCTION

Under the double pressure of energy crisis and environmental pollution, the construction of integrated energy system (IES) has drawn widespread attention all over the world [1], for its higher energy comprehensive utilization efficiency and emission reduction value.

The regional energy station is the multi-energy coordinated operation center of IES. The mutual conversion of multiple energy sources can improve the economy, flexibility and reliability of the system, and flexibly meet the energy needs of multiple loads [2]. So the energy management strategy of the energy station is essential for both operators and customers. In [3], a new home energy management framework is established with the objective of reducing energy cost considering the constraints of different components of energy hubs. The recombination particle swarm optimization algorithm is used to study the optimal strategy of energy management in microgrid aiming at minimizing operation cost and maximizing user satisfaction [4]. [5] uses the potential game method to model the energy hubs interaction, considers its real-time scheduling problem in the dynamic pricing market, and optimizes the energy hubs operating cost and user satisfaction.

In recent years, the double auction form has developed rapidly in the energy trading market, and its role in the coordinated allocation of energy stations and the optimization of energy use has gradually gained more attention. So, in this paper, the double auction-based energy management method is proposed for regional energy station.

The main contributions of this paper are as follows:

(1) The energy management framework of the regional energy station is proposed based on the double auction market, which provides new ideas of utilizing economic behavior to manage energy supply and demand.
(2) The regional energy station model and the electric/heat bidding model are established considering the users' comfort.
(3) The market clearing model is constructed with the aim of maximizing the surplus of both energy producers and consumers, achieving the optimization of the interests of both parties.

2. ENERGY MANAGEMENT FRAMEWORK OF REGIONAL ENERGY STATION BASED ON DOUBLE AUCTION MARKET

In this paper, the coordinated double auction market in terms of electricity and heat is utilized to achieve the coordinated clearing of two forms of energy. The energy management framework is proposed to optimize the energy allocation of energy station and the energy consumption of customers. The diagram is shown in Fig.1. In the proposed framework, the regional energy station is in charge of supplying electricity and heat to customers, in which there are many energy generation, conversion and coupling devices, such as combined heat and power (CHP), power electronic converter (PEC) and so on. And for electric and heat customers, under the condition of multi-energy complementarity, they can optimize the energy use by converting energy sources from energy stations or changing the energy usage behavior. The coordinated double auction market is an important trading platform for the energy station and users under its jurisdiction. The electric and heat customers submit buy bid to the market while the energy station provides marginal costs of various devices to the coordinated market. The market clears at specific intervals with the aim of maximizing the production and consumption surplus. After clearing, the energy station supplies energy to the customers and users adjust their energy consumption.

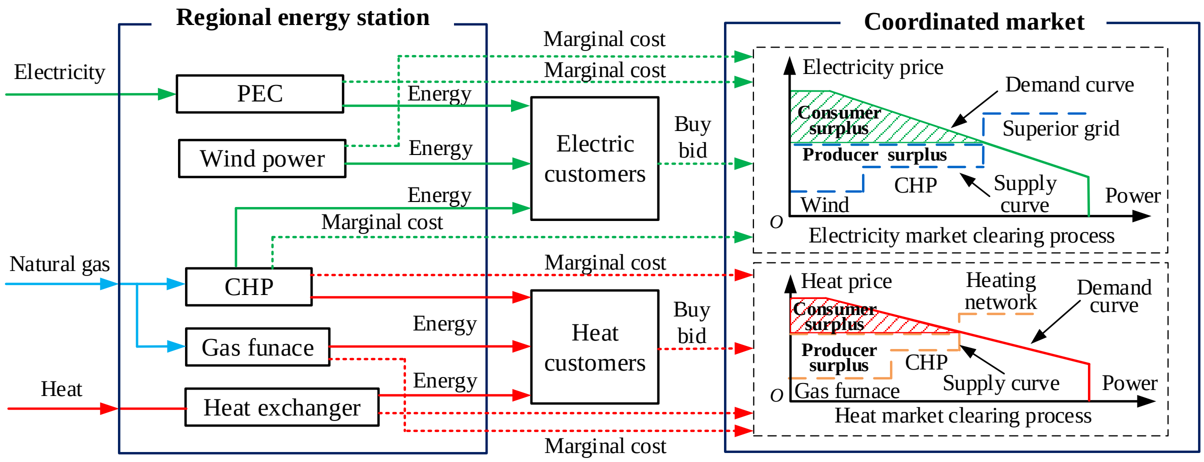

Fig.1 Diagram of energy management strategy for regional energy station

3. MODEL CONSTRUCTION

3.1 Energy station model

The energy station is an important energy coupling center, and in this paper, its main equipment includes PEC, CHP, gas furnace (GF), heat exchanger (HE) and wind turbines. The diagram is shown in Fig.2.

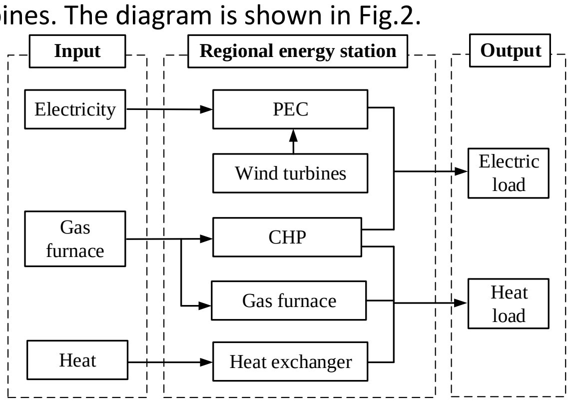

Fig.2 Schematic of regional energy station

As shown in Fig.2, the electric load is satisfied through superior grid and the distributed energy together with the power generated by CHP; as for the heat load, part of it is met by the input heat supplied through superior network, and the other part is satisfied by the heat generated by CHP and GF. The system subjects to the following energy equation:

$$\begin{bmatrix} L_e \\ L_h \end{bmatrix} = \begin{bmatrix} \eta^{PEC} & \lambda_1 \eta_{ge}^{CHP} & 0 & 1 \\ 0 & \lambda_1 \eta_{gh}^{CHP} + (1-\lambda_1)\eta^{F} & \eta^{HE} & 0 \end{bmatrix} \begin{bmatrix} P_e \\ P_g \\ P_h \\ P_{WT} \end{bmatrix} \quad (1)$$

Where L_e and L_h are electric and heat load demand, η_{ge}^{CHP} and η_{gh}^{CHP} are the efficiency of using CHP to produce electricity and heat, η^{F} is the efficiency of using GF to produce heat, η^{F} and η^{HE} are the energy conversion efficiency of PEC and HE, P_e、P_g、P_h and P_{WT} are the input energy flow for electricity, natural gas, heat and wind turbines, λ_1 is the partition coefficient, which indicates the proportion of natural gas flowing through CHP.

3.2 Electric/heat load bidding model

In winter, the main energy consumption comes from electric and heat load. Traditional energy management methods of energy stations typically treat the load as static and haven't taken into account the resource allocation role of the market. So in this paper, the price elasticity of the load is utilized to realize active energy management of energy stations and customers.

For electric load, the energy demand of some devices is not affected by electricity price, such as lights, and we call them inelastic load. They participate in the auction at the highest price. While some devices can respond to price because of their energy storage capacity such as electric water heater, and we call them elastic load. In this paper, the electric water heater is selected as elastic load. For this kind of load, each user submits a buy bid for specific power, which can be expressed as follows.

$$p_{\text{e\_bid}} = p_{\text{e\_a}} + (T_i - T_{\text{set}})\frac{k_{\text{T}} \times \sigma_{\text{e}}}{|T_{\max} - T_{\text{set}}|} \tag{2}$$

$$T_{\min} \le T_i \le T_{\max} \tag{3}$$

Where $p_{\text{e\_bid}}$ is bidding price; $p_{\text{e\_a}}$ is average electricity price of the last three hours and σ_{e} is standard deviation; T_i is the current water temperature of *i*th device; T_{set} is desired temperature; k_{T} is pre-defined comfort; $T_{\min}$ and $T_{\max}$ is the temperature limit.

For heat load, the space heating load is selected as elastic load due to the heat storage capacity of residential buildings. The bidding model of space heating load can be formulated as follows. In the proposed model, the heat power varies linearly with price.

$$\begin{cases} p_{\text{h\_bid\_min}} = p_{\text{h\_a}} + (Q_{\min} - Q_{\text{set}})\dfrac{k_Q \times \sigma_{\text{h}}}{|Q_{\max} - Q_{\min}|} \\ p_{\text{h\_bid\_max}} = p_{\text{h\_a}} + (Q_{\max} - Q_{\text{set}})\dfrac{k_Q \times \sigma_{\text{h}}}{|Q_{\max} - Q_{\min}|} \end{cases} \tag{4}$$

$$Q_{\min} \le Q_i \le Q_{\max} \tag{5}$$

Where Q is the heat power input of single residential building; $p_{\text{h\_a}}$ is the average heat price and σ_{h} is its standard deviation.

According to the buy bid, the demand curve of electricity and heat can be obtained by superposition. For electric load, the demand curve is formed by summing every user's demand power with ordered bidding price. For heat load, the demand curve is obtained by cumulating bidding curve of every building.

3.3 Market clearing model based on supply and demand bidding

After receiving the demand curve and the marginal costs of devices in the energy station, the coordinated market clears with the aim of maximizing producer and consumer surplus, achieving the optimal allocation of energy resources and energy usage.

(1) Objective function

$$\begin{cases} \max\left(Sur_{\text{ele}} + Sur_{\text{heat}}\right) \\ Sur_{\text{ele}} = p_{\text{clear\_ele}} L_{\text{e}} - \sum\limits_{k \in (\text{EN,CHP,W})}^{m} S_k p_k P_k + \left(L_{\text{e}} + L_{\text{e,min}}\right) \times \left(p_{\text{ele\_max}} - p_{\text{clear\_ele}}\right)/2 \\ Sur_{\text{heat}} = p_{\text{clear\_heat}} L_{\text{h}} - \sum\limits_{l \in (\text{CHP,GF,HN})} S_l p_l P_l + \left(L_{\text{h}} + L_{\text{h,min}}\right) \times \left(p_{\text{heat\_max}} - p_{\text{clear\_heat}}\right)/2 \end{cases} \tag{6}$$

Where $p_{\text{clear\_ele}}$ and $p_{\text{clear\_heat}}$ are market clearing price of electricity and heat; S is a binary variable representing selection of various electricity and heat generation resources; p is the marginal cost of devices in energy station.

(2) Constraints

1) Natural gas input constraint:

$$P_{\text{g\_min}} \le P_{\text{g}} \le P_{\text{g\_max}} \tag{7}$$

2) Output of CHP constraint:

$$P_{\text{CHP\_min}} \le P_{\text{CHP}} \le P_{\text{CHP\_max}} \tag{8}$$

3) Upper and lower limit constraints of electric and heat load:

$$\begin{cases} L_{\text{e\_min}} \le L_{\text{e}} \le L_{\text{e\_max}} \\ L_{\text{h\_min}} \le L_{\text{h}} \le L_{\text{h\_max}} \end{cases} \tag{9}$$

4. CASE STUDY

In this section, we utilize the regional energy station described in 3.1 to test the effect of the proposed method on optimizing resource allocation of the energy station and guiding energy use behavior of customers. The conversion efficiency of devices is shown in Table 1. 300 electricity and heat users in winter are simulated. The space heating energy demand are satisfied through CHP, superior heating network or gas furnace located in the regional energy station. The electric load can be met by superior grid, wind power or CHP. The elastic loads are those described in 3.2. The market clearing interval is set to be 15mintes.

Table 1. Devices parameters

Equipment name	Energy type	Efficiency
PEC	Electricity	1
CHP	Electricity/heat	0.3/0.4
Gas furnace	Heat	0.85
Heat exchanger	Heat	0.95

(1) Coordinated market clearing process

The market clearing process at two typical moments is shown in Fig.3 and Fig.4.

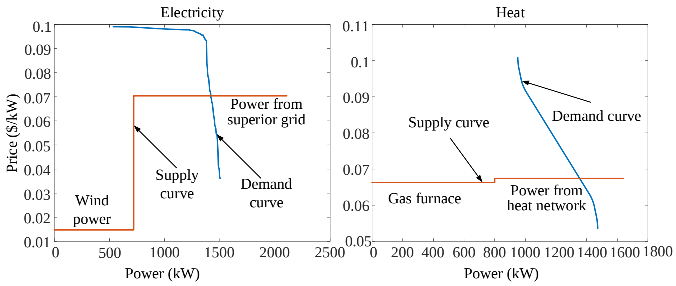

Fig.3 Market clearing process at interval of 59

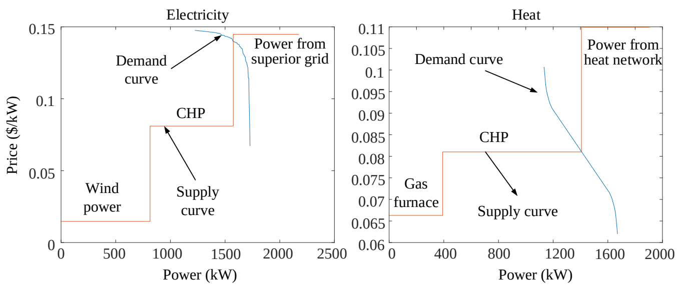

Fig.4 Market clearing process at interval of 77

As shown in Fig.3, at approximately 14:45, the electricity and heat price of superior network are both in the valley, so customers choose wind power and electricity of superior grid to meet electric demand. CHP are not selected because the marginal cost is high. For the same reason, customers use heating network and gas furnace to satisfy their heat demand.

As shown in Fig.4, in the interval of 77, about 19:15, the electricity and heat price of superior network are both at their peak, so customers use CHP to meet the remaining electric and heat demand except wind power and gas furnace. The market clearing prices are obtained through market clearing model.

(2) Coordinated market clearing results

The market clearing results of the energy station is shown in Fig.5.

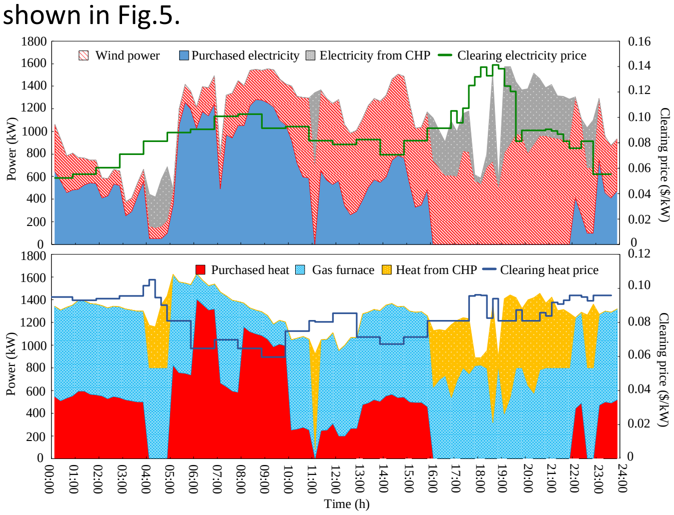

Fig.5 market clearing results of the energy station

It can be observed that when the marginal cost of superior network is high, the CHP is prioritized to be utilized for generating energy. In contrast, the energy from superior network is first chosen when the marginal cost is at valley. We can also see that the electricity and heat organically coupled through energy coupling device such as CHP, leading to mutual constraint of electricity and heat.

(3) Energy saving effect of the proposed method

The comparison between the proposed method and the load without bidding is shown in Fig. 6.

Table 2. Load reduction comparison

Load type	Electric load	Heat load
Load reduction (kWh/day)	182.2	1364.1
Load reduction ratio	0.6%	4.3%

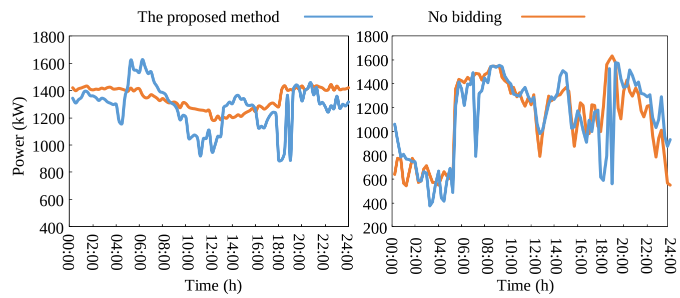

Fig.6 Load reduction and shift effect

As shown in the figure, when the market clearing price is high, the customers reduce energy consumption to save energy expenditure, while when the energy price is low, they increase energy demand to pre-heat, making full use of the energy storage characteristics and demand elasticity of the load.

As shown in Table 2, the electric load and heat load reduction ratios are 0.6% and 4.3%, respectively. Meanwhile through load reduction and load shift, users can save more energy expenditure.

5. CONCLUSIONS

This paper proposes a new energy management strategy of the region energy station based on double auction retail energy market. The energy station model and load bidding model are constructed. The market clearing model is established with the aim of maximizing the total of producer and customer surplus. The case study verifies the positive effect on optimizing the resource allocation and guiding users' energy consumption. The proposed method provides a new idea for energy management of energy stations.

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