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Integrated Energy Purchase-Sale Decision Making and Scheduling for Integrated Energy Service Provider Considering User Grading Dynamic Combination

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Abstract. In an open energy market environment, energy retail competition is intensifying. integrated energy service provider (IEPS) with the right to operate regional integrated energy system. Under the requirement of distributed resource transaction access and scheduling security, how to integrate multi-level and multi-type user resources to participate in market operation, allocate resources within the region under its jurisdiction and improve the income of energy purchase and sale is the key for IESP to gain a favourable position in the market competition. Based on the operation framework of IESP including user grading and dynamic combination platform, integrate real-time dynamic combination of user resources into optimal scheduling, aiming at the operating economy of IEPS, an integrated energy purchase-sale decision making and scheduling method for IEPS considering user grading dynamic combination is proposed. Finally, an example is given to analysis through the regional integrated energy system with electric-gas-heat coupling. The results show that by reasonably combining users and scheduling distributed energy and adjustable load. The IESP can ensure the stable operation of the regional energy system, integrate and utilize decentralized resources to participate in the market, and maximize the economic benefits of energy purchase and sale.

1 Introduction

In the context of global efforts to develop renewable energy, integrated energy system and energy marketization, user-side resources are also more willing to participate in market transactions [1]. The integrated energy trading with electricity, gas and heat as the main energy sources develops rapidly, and the transformation from traditional energy services to comprehensive energy services has become the focus of energy enterprises [2].

Integrated energy trading market framework with integrated energy system (IES), integrated energy service provider (IESP) and integrated energy user (IEU) as the core will become the future development trend. Among them, as a participant in the integrated energy market, IESP can provide users with a variety of integrated energy services and participate in market competition on behalf of users. With distributed energy sources such as combine heat and power (CHP), electric boiler (EB), energy storage system (EES), wind power and photovoltaic power generation as the core, IES can make efficient use of local resources. The IEU has user-side resources that are responsive and adjustable. The emergence of IESP makes the user-side integrated energy market possible.

At present, the research on integrated energy market mainly involves energy interconnection [3-4], energy aggregation [5], market transaction [6-9], demand response [10] and other aspects. However, the existing researches rarely involve the multi-grade entry threshold of user-side resource participation in integrated energy trading. The research on IESP purchase-sale decision making and scheduling considering user grading dynamic combination is not comprehensive.

This paper takes IESP that aggregate distributed energy on the user side and its purchase-sale decision making and scheduling plan as the research object. The main innovations are as follows:

- The user grading dynamic combination (UGDC) method is proposed, which is conducive to making full use of user resources that are distributed, irregular and of small capacity grade.
- The framework of regional power, natural gas market and local heat market is proposed, which is conducive to clarifying the linkage between the three types of energy markets.
- An IESP purchase-sale decision making and scheduling method considering UGDC strategy is proposed. It is beneficial for IESP to integrate and utilize decentralized resources to participate in the market and maximize the economic benefits of IESP.

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2 Operation mode of IESP

2.1 Structure of integrated energy market

This paper divides the integrated energy market into a three-level structure, including regional energy markets, local heat market, IEU. The regional energy markets include electricity and natural gas markets. The local heating market is dominated by IESP. IEU includes demand response, renewable power generation and other distributed energy resource (DER).

2.2 Operating framework of IESP

IESP integrates DER mainly including distributed generation (DG) and DL mainly including interruptible load (IL) and translatable load (TL) within its territory to participate in the scheduling of IESP. The operating framework of IESP with UGDC is shown in Figure 1. Hierarchical grouping of users based on external features, combining to form power supply user (PSU), interrupt load user (ILU) and translational load user (TLU), according to the adjustable load capacity and available energy of each resources' electricity, gas and heat. It can be set to level 1 and level 2 indicators that are $G_{\mathrm{e},1}$, $G_{\mathrm{e},2}$, $G_{\mathrm{g},1}$, $G_{\mathrm{g},2}$, $G_{\mathrm{h},1}$, $G_{\mathrm{h},2}$. The resource scheduling is divided into first, second and third levels. Through the UGDC trading platform, IESP aggregated the scattered DER and DL in different grades in the local area under its jurisdiction into UGDC with several external features including PSU, ILO, and TLU, and responded to the scheduling plan issued by IESP.

2.3 Transaction mode of IESP

The scheduling mode and decision-making process of the IESP are shown in Figure 2. IESP purchases and sells energy according to the process corresponding to the time points of *t*-1day, *t*-30min, *t*-15min, *t* min and the end of the month.

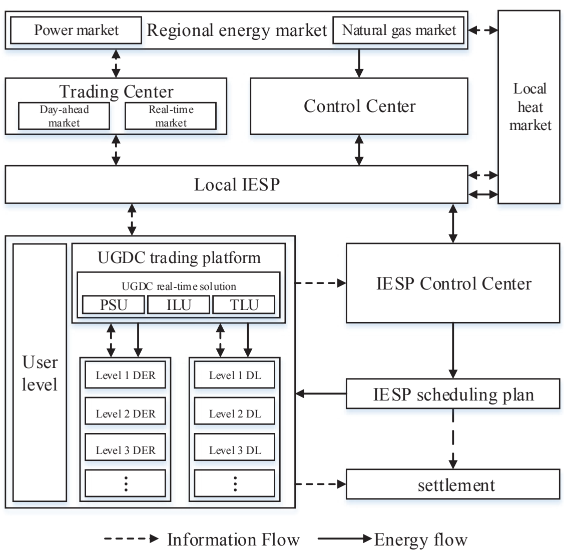

Figure 1. IESP operational framework

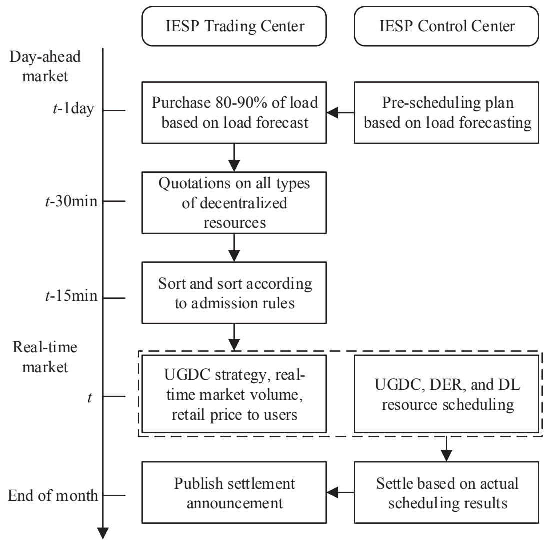

Figure 2. IESP schedule and purchase-sale flow.

3 Purchase-sale decision making and scheduling model for IESP considering UGDC

3.1 UGDC model

DER, IL, DL and other distributed resources are combined according to user level to make them meet transaction access requirements and participate in the scheduling of IESP. The combination mode is as follows:

$$
\begin{aligned}
C_{\mathrm{U}} = \Delta T \sum_{t=1}^{T} [& \sum_{s} \sum_{d}^{D} (\rho_{d,s}^{\mathrm{PSU}} \sum_{e}^{E} N_{e,s}^{\mathrm{PSU}} P_{e,s,t}^{\mathrm{DER}}) + \\
& \sum_{s} \sum_{h}^{H} (\rho_{h,s}^{\mathrm{ILU}} \sum_{k}^{K} N_{k,s}^{\mathrm{ILU}} P_{k,s,t}^{\mathrm{IL}}) + \\
& \sum_{s} \sum_{l}^{L} (\rho_{l,s}^{\mathrm{TLU}} \sum_{g}^{G} N_{g,s}^{\mathrm{TLU}} P_{g,s,t}^{\mathrm{TL}})]
\end{aligned} \tag{1}
$$

Where C_{U} is the scheduling cost after UGDC. *D*, *H* and *L* are respectively the number of PSU, ILU and TLU. *E*, *K* and *G* are respectively the number of DER, IL and TL users. $\rho_{d,s}^{\mathrm{PSU}}$ is the unit cost of the s^{th} energy adjustment of the d^{th} PSU. According to the resource scheduling index, it is a three-step signal. N_e^{PSU} is 0-1 variable, when equal to 1, means that the e^{th} DER's the s^{th} energy participates in the combination to form the d^{th} PSU. When equal to 0, it does not participate in the combination. $P_{e,s,t}^{\mathrm{DER}}$ is the e^{th} DER's the s^{th} energy output in time *t*. $\rho_{h,s}^{\mathrm{ILU}}$ is the unit cost of the h^{th} IL's the s^{th} energy scheduling. According to the resource scheduling index, it is a three-step signal. $N_{k,s}^{\mathrm{ILU}}$ is 0-1 variable, when equal to 1, it means that the k^{th} IL's the s^{th} energy participate in the combination to form the h^{th} ILU. When equal to 0, it does not participate in the combination. $P_{k,s,t}^{\mathrm{IL}}$ is the load interruption of the k^{th} IL's the s^{th}. $\rho_{l,s}^{\mathrm{TLU}}$ is the unit cost of the l^{th} TLU's the

s^{th} energy scheduling, according to the resource scheduling index, it is a three-step signal. $N_{g,s}^{\text{TLU}}$ is 0-1 variable, when is equal to 1, it means that the g^{th} TL's the s^{th} energy participates in the combination to form the l^{th} TLU. When is equal to 0, it does not participate in the combination. $P_{g,s,t}^{\text{TL}}$ is the load translation of the g^{th} TL's the s^{th} energy.

3.2 IESP optimal scheduling model

3.3.1 Optimization objective

The optimization goal of IESP is to maximize the purchase-sale revenue, which consists of the energy retail revenue, the day-ahead market purchase cost, and the user demand response cost.

$$\begin{aligned}\max F = \Delta T \sum_{t=1}^{T}\sum_{s}\{\rho_{t,s}^{\text{sell}}[\sum_{i=1}^{N} P_{i,s,t}^{\text{L}} - \sum_{k=1}^{K}(1-N_{k,s}^{\text{ILU}})P_{k,s,t}^{\text{IL}} - \\ \sum_{g=1}^{G}(1-N_{g}^{\text{TLU}})P_{g,s,t}^{\text{TL}} - \sum_{m=1}^{M} P_{m,s,t}^{\text{U}}] - \\ \rho_{t,s}^{\text{d}}P_{t,s}^{\text{d}} - \rho_{t,s}^{\text{r}}P_{t,s}^{\text{r}} - \sum_{e=1}^{E}\rho_{e,s}^{\text{DER}}(1-N_{e,s}^{\text{PSU}})P_{e,s,t}^{\text{DER}} - \\ \sum_{k=1}^{K}\rho_{k,s}^{\text{IL}}(1-N_{k,s}^{\text{ILU}})P_{k,s,t}^{\text{IL}} - \\ \sum_{g=1}^{G}\rho_{g,s}^{\text{TL}}(1-N_{g,s}^{\text{TLU}})P_{g,s,t}^{\text{TL}}\} - C_{\text{U}}\end{aligned} \quad (2)$$

Where F is the profit of the whole day of IESP. ΔT is the length of a scheduling session. T is the total number of time periods of a scheduling cycle. $\rho_{t,s}^{\text{sell}}$ is the price of the s^{th} energy sold to user in time t. N and M are respectively the number of system nodes and the number of UGDC. $P_{i,s,t}^{\text{L}}$ is the user integrated load at node i at time t. $P_{m,t}^{\text{U}}$ is scheduling amount of the m^{th} UGDC at time t. $\rho_{t,s}^{\text{d}}$ and $P_{t,s}^{\text{d}}$ are day-ahead market price and purchase amount. $\rho_{t,s}^{\text{r}}$ and $P_{t,s}^{\text{r}}$ are price and transactions of IESP in the real-time market, when $P_{t,s}^{\text{r}} > 0$, purchase the s^{th} energy from real-time market. When $P_{t,s}^{\text{r}} < 0$, sell the s^{th} energy to real-time market. $\rho_{e,s}^{\text{DER}}$ is the unit payment cost of the e^{th} DER's the s^{th} energy. $P_{e,s,t}^{\text{DER}}$ is the energy output of the e^{th} DER's the s^{th} energy. $\rho_{k,s}^{\text{IL}}$ is the unit cost for load interruption of k^{th} IL's the s^{th} energy. $\rho_{g,s}^{\text{TL}}$ is the unit cost for load translation of the g^{th} TL's the s^{th} energy.

3.3.2 The constraints

The constraints involved in the model established in this paper are as follows: electricity flow constraint, natural gas flow constraint, heat flow constraint, electric-gas-heat coupling constraint, IL contractual constraint, TL contractual constraint, DER constraints, UGDC scheduling constraints, energy storage operating constraint, real-time market trading constraints.

4 Case Study

4.1 Case setting

As shown in Figure 3, electricity grid node 1 is connected to the main network, while natural gas pipeline node 1 is connected to the main network. The 11 nodes of the heat network are connected with the 5 nodes of the electricity grid and the 5 nodes of the natural gas pipeline through coupling equipment. In this locality, there are 6 users. Their detailed data is shown in table 1. E4, G6 and H11 are connected to EES, GES and HES respectively, with capacities of 120, 100 and 100kW respectively. Energy storage charging and discharging efficiency of 95% and 90% respectively. For TL, set the shift interval is 4h. Set the grading index of electricity, gas and heat user participation $G_{\text{e},1}$, $G_{\text{e},2}$, $G_{\text{g},1}$, $G_{\text{g},2}$, $G_{\text{h},1}$, $G_{\text{h},2}$ as 110kW, 220kW, 40kW, 60kW, 18kW and 35kW.

Table 1. User data.

user	location	type	The maximum capacity (kW)
U1	E2	PS	150
	G3	TL	30
	H9	TL	30
U2	E3	PS	100
	G7	TL	30
	H8	TL	30
U3	E4	IL	200
	G8	TL	100
	H7	IL	30
U4	E5	PS	200
	G5	IL	100
U5	G2	TL	40
U6	H10	IL	40

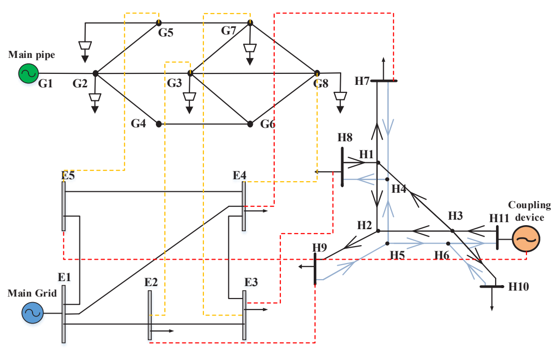

Figure 3. Integrated energy system with electricity, gas and heat coupling.

4.2 result analysis

4.2.1 UGDC strategy

Table 2. UGDC strategy.

T	UGDC	U	User electricity scheduling (kW·h)	User gas scheduling (kW·h)	User heat scheduling (kW·h)
a	UGDC1	U1	1159	120	40
		U2	759	97	40
		U4	1526	68	/
	UGDC2	U3	1309	302	82
		U5	/	124	/
		U6	/	/	52
b	UGDC3	U3	653	763	174
		U5	/	304	/
c	UGDC4	U3	0	326	232
		U6	/	/	315

Table 2 shows the UGDC strategy, showing the condition of combined invocation of PS, IL and TL resources. According to the multi-energy load curve, 24h a day is divided into three periods, each of which is 8h long, namely 8-11h and 18-21h, 12-17h and 22-23h, 1-7h and 24h, respectively denoted as *a* period, *b* period and *c* period.

4.2.2 IESP user resource scheduling

Figure 4 shows the invocation of user resources by IESP within 24 hours of one day, the dotted lines in the figure represent the grade access levels of electricity, gas and heat. According to Figure 4, the heat resources of U1 and U2 cannot meet the admission requirements of $G_{h,1}$, but after UGDC1, the heat resources of U1 and U2 meet the admission requirements of $G_{h,1}$. They are scheduled and successfully participate in the heat trade. The heat resources of U3 and U6 meet the requirements of heat $G_{h,1}$, but to participate in the market is limited, restricted by its maximum capacity, not by $G_{h,2}$ entry requirements. But through UDGC4, both heat resources to $G_{h,2}$. They success in a higher level of hot deals.

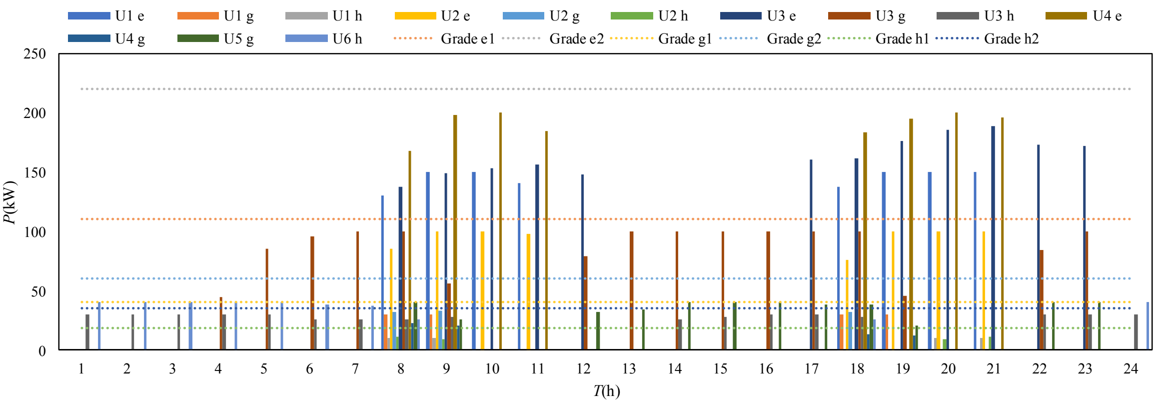

Figure 4. IESP user resource scheduling strategy.

5 Conclusion

This paper takes the IESP with the operation right of the local IES as the research object. Aiming at the difficulty of access and regulation of distributed resources in the local area, an optimal scheduling model of the IESP considering UGDC strategy is established. Through the analysis of the example, the validity of the proposed method is proved.

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