Modeling and Strategic Design of Multi-Layered Aggregation and Control for Flexible Loads

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November 19, 2023

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***Abstract*—With continuous development of new energy generation, there is an urgent need to enhance the regulation capabilities of the power system. This paper is dedicated to transforming potential flexible load resources into practically adjustable system resources, and a three-layer aggregation and control framework presented, i.e "User - Load Aggregator - Grid Operator." Optimal decision-making models for three types of market entities are presented, including electricity consumption strategies of users, bidding strategies of load aggregators, and regulation resource procurement strategies of the system operator. The supply-demand difference caused by generation output fluctuations of intermittent renewable energy resources is examined, and source-load regulation resources are employed in the day-ahead ancillary service markets, especially the regulation market. Case studies are carried out to demonstrate the feasibility and efficiency of the proposed multi-layer aggregation and control model together with associated strategies in achieving optimal employment of flexible loads, and the effects of load aggregators' profits and grid operators's dispatch on balancing power supply and load demand.**

Keywords—Flexible load, load aggregator, aggregation and control, quantity-price optimization.

I. INTRODUCTION

With the increasing share of new energy generation and the development of modern power systems, the power system urgently needs to find new ways to enhance its regulation capabilities. The demand side, with a large amount of potential adjustable resources, is becoming increasingly important, especially with the rapid growth of emerging loads such as electric vehicles and energy storage. We define such loads with adjustable power characteristics as flexible loads. Exploring regulation resources on the demand side, transforming the traditional source-following load into source-load interaction, and enhancing the power system's regulation capabilities are crucial for ensuring the secure and economic operation of a modern power system.

An efficient participation mechanism of flexible loads in different electricity markets has not yet been systematically investigated, and many issues remain to be studied and demonstrated. Ref [1] points out that China has not yet truly realized the automatic adjustment of load resources through continuous power to participate in regulation business, especially concerning a large number of dispersed load resources represented by electric vehicles and distributed energy storage. At present, the participation of aggregated flexible loads, such as electric vehicles, energy storage, air conditioning, electric heating, and lighting,,in providing regulation services, is a problem with extensive concerns, and many forward-looking studies have been conducted worldwide [2-4]. Technical issues related to load resources participating in the electricity market are focused in [5], such as operational mechanisms, regulation strategies, and load potential. The analysis shows that the participation of load resources in the electricity market can optimize users' electricity usage patterns. An energy storage peak-shaving day-ahead optimization scheduling strategy that takes into account the load peak-valley characteristics is proposed in [6]. The results indicate that fully utilizing energy storage systems to achieve optimal peak shaving and valley filling can significantly reduce the daily average wind power curtailment. Regarding research on load aggregators, a bidding and compensation strategy is proposed in [7] for load aggregators with direct control capabilities for temperature-controlled loads. Simulation results demonstrate that load aggregators can bring significant profits through direct load control capabilities. A multi-agent Nash game model is developed in [8] to achieve collaborative decision-making among multiple intelligent agents, such as power storage enterprises and power source enterprises. A three-tier interactive decision model is proposed in [9] for the participation of demand-side resource aggregation response entities in a two-tier electricity market.

Existing research mostly focuses on the user side, the grid operator side, or considers the two-layer optimization of load aggregator-users. There is relatively less research on the overall three-layer optimization control architecture of a large-scale flexible load group centered around a load aggregator. Additionally, there is limited research on the analysis of interests among multiple market entities, including users, load aggregators, and grid operators, and the overall optimal allocation of resources.

This paper takes the participation of a flexible load group in electricity peak shaving as an example, investigates and analyzes the three-layer market entity's game relationships among users, load aggregators, and grid operators. A market structure is designed for flexible load aggregation control with a layered interaction, and a simulation system developed. The equilibrium points for the three-layer market entities are

This work is supported by a research and development project entitled "Coordinated Operation and Market Mechanism Research of Integrated Source-Network-Load-Storage Projects in Power Systems" (Project No. 1400-202333325A-1-1-ZN; Contract No.: SGTYHT/21-JS-223).

attained, and the optimal utilization of flexible load resources achieved.

II. MARKET MECHANISM DESIGN FOR AGGREGATED CONTROL OF FLEXIBLE LOAD GROUPS.

A. *Market Process for Optimized Control of Flexible Load Groups.*

In Figure 1, the architecture for the participation of flexible load aggregation in electricity peak load assistance services, with load aggregators as intermediaries, is vertically divided into three layers: the grid operator layer, load aggregator layer, and user layer. Horizontally, it includes three processes: load aggregation control plan generation, control plan decomposition and load de-aggregation, and closed-loop control of control plan execution. Overall, it achieves hierarchical and zonal aggregation control of flexible loads.

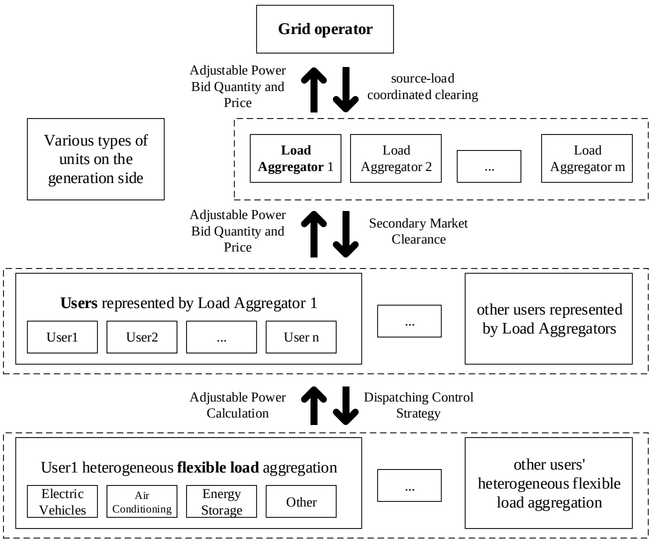


Fig. 1. Hierarchical Relationships among Grid Operators, Load Aggregators, and Users.

III. MARKET ARCHITECTURE FOR THE AGGREGATION CONTROL OF FLEXIBLE LOAD WITH LAYERED INTERACTION

A. *User Quantity-Price Response Strategy Model Considering Satisfaction and Bid Success Rate.*

In the interaction between users and load aggregators, users need to report peak response capacity and incentive prices to the load aggregator. Users must consider a rational decision for bid quantity and price to maximize their own interests and enhance the likelihood of successful bids. Meanwhile, the power adjustment of flexible loads affects user comfort. Therefore, a dual-objective optimization model is presented to determine the adjustment amount and incentive price of their flexible loads, aiming to achieve maximum benefits in the market.

1) Optimization Objectives

a) Optimization Objective 1: Maximize User Expected Revenue.

The income obtained by users from participating in peak load assistance services within a day consists of two parts: the first part is the incentive revenue from the user's participation in peak load assistance services with flexible loads, and the second part is the daily electricity cost saved by the user due to adjusting their electricity consumption.

$$W_{user,a} = W_{user,save} + W_{user,dr} \tag{1}$$

where $W_{user,a}$ represents the daily income obtained by users for participating in demand response (in yuan), $W_{user,save}$ represents the electricity cost saved by users after adjustment (in yuan), and $W_{user,dr}$ represents the electricity cost for the incentive charges incurred by users participating in the regulation (in yuan).

The formula for calculating $W_{user,save}$, the reduction in electricity cost expenditure due to users changing their electricity consumption behavior is:

$$W_{user,save} = \int_0^{24} C_{real-time}(t)\Delta P_{user}(t)dt \tag{2}$$

where $C_{real-time}(t)$ is the daily real-time electricity price (in yuan/kWh), and $\Delta P_{user}(t)$ is the user's adjustable load power (in kW). The user's adjustable load power $\Delta P_{user}(t)$ is the difference between the load baseline and the load after adjustment, calculated as:

$$\Delta P_{user}(t) = P_{user-dr}(t) - P_{user-base}(t) \tag{3}$$

$$P_{user-dr}(t) = P_{dr-TCL}(t) + P_{dr-ES,i}(t) + P_{dr-EV}(t) \tag{4}$$

$$P_{user-base}(t) = P_{base-TCL}(t) + P_{base-ES}(t) + P_{base-EV}(t) \tag{5}$$

where $P_{user-dr}(t)$ is the 24-hour electricity consumption power of the user after responding to the daily adjustment, $P_{user-base}(t)$ is the 24-hour baseline power of the user after responding to the daily adjustment, and TCL represents air conditioning, ES represents energy storage, and EV represents electric vehicles. The baseline load is the average load of users on the five days before participating in the auxiliary service event.

The goal of maximizing user profit is composed of the bid probability function and the profit function, where the user's incentive fee and bid probability obtained after participating in regulation are:

$$W_{user,dr} = \int_{t_0}^{t_1} C_{user}\Delta P_{user}(t)dt \tag{6}$$

$$p_{user} = \left(\frac{1}{2} - \frac{1}{\pi}\arctan(C_{user} - \overline{C_{user}})\right) \times 100\% \tag{7}$$

where $C_{user,dr}$ is the user's quotation for participating in the day-ahead peak load assistance service (in yuan), $\overline{C_{user}}$ is the quotation at which the user has a 50% bid success rate (in yuan), and p_{user} is the bid success probability of the user when the price is C_{user}. The optimization goal for maximizing user expected revenue is:

$$\max W_{user,\exp} = p_{user} W_{user,a} \tag{8}$$

b) Optimization Objective 2: Optimizing User Electricity Satisfaction

Assuming that before participating in electricity auxiliary services, the user's satisfaction is optimal, the change in user electricity consumption will have a certain impact on their satisfaction. This paper uses the following formula to fit the relationship between user satisfaction and changes in electricity consumption:

$$W_{user,b} = e^{\lambda \Delta P_{user}} \tag{9}$$

where $W_{user,b}$ is the user's dissatisfaction with electricity consumption, ΔP_{user} is the average user's adjustable load power (in kW), and λ is the sensitivity of the user to the decrease in electricity consumption.

where the average user's adjustable load power is:

$$\Delta P_{user} = \int_{t_0}^{t_1} \Delta P_{user}(t)dt / (t_1 - t_0) \tag{10}$$

where $\Delta P_{user}(t)$ is the average user's adjustable load power (in kW), and [t_0 , t_1] represents the time period during which the user participates in electricity peak load (in min).

c) Dual-Objective Optimization of User Satisfaction and Expected Revenue

In consideration of the bidding success rate, simultaneously optimizing user satisfaction and user revenue under this premise, a dual-objective optimization function is constructed as follows:

$$\begin{cases} \max W_{user,\exp} = p_{user} W_{user,a} \\ \min W_{user,b} = e^{\lambda \Delta P_{user}} \end{cases} \tag{11}$$

2) Constraints

a) User participation in auxiliary service quotations and time-of-use electricity prices are both greater than 0:

$$\begin{cases} C_{user,dr} > 0 \\ C_{real-time} > 0 \end{cases} \tag{12}$$

b) Optimize on a daily basis:

$$[t_0, t_1] \subseteq [0, 24] \tag{13}$$

c) Considering user comfort requirements, the temperature range for air conditioning load is set to [22℃, 28℃]:

$$22℃ \le T_{set}(t) \le 28℃ \tag{14}$$

d) Energy storage load constraint:

Considering the battery's lifespan, there are certain constraints on the state of charge of the energy storage:

$$SOC_{ES,\min} \le SOC_{ES}(i) \le SOC_{ES,\max} \tag{15}$$

where $SOC_{ES}(i)$ is the state of charge of the i-th energy storage at that moment (%), and $SOC_{ES,\min}$ is the lower limit value of the state of charge for energy storage.

e) Electric vehicle load constraint:

For electric vehicles, there is a constraint relationship similar to that of energy storage:

$$SOC_{EV,\min} \le SOC_{EV}(t) \le SOC_{EV,\max} \tag{16}$$

B. Load Aggregator Pricing Response Strategy Model Considering User Benefits and Bid Success Rate.

This layer of the model is designed for load aggregators participating in the peak load assistance services of the power grid. It explores how load aggregators can balance user benefits with the peak demand requirements of the grid operator, taking into account the bid success rate. This involves decision-making regarding the selection and utilization of user flexible load resources, as well as decisions on participation in the peak load assistance service market in terms of volume and pricing.

Load aggregators primarily operate by taking the difference between the incentive compensation from the grid operator and the incentive expenditure paid to the represented users for resource utilization. They achieve their business model by charging a representation fee. Therefore, the goal of load aggregators is to maximize the aggregation of represented load resources participating in grid interactions to obtain revenue.

1) Optimization Objectives

According to the variation in power load, each day is divided into n time periods. Load aggregators use the peak demand published by the grid operator for a specific time period as a basis. Combining this with the aggregation of flexible load resources, load aggregators participate in the market by declaring the quantity and price for electricity peak load assistance services. The profit calculation formula for load aggregators participating in the market is as follows:

$$F_{LA} = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{i,j} W_{i,j}^{user} (C_j^{LA} - C_{i,j}^{user}) \tag{17}$$

where F_{LA} is the revenue obtained by the load aggregator participating in the market (in yuan), $x_{i,j}$ is the bidding result declared by the i-th aggregated user in the j-th adjustment period(1 indicates that the user is selected by the load aggregator, and 0 indicates that the user is not selected), $W_{i,j}^{user}$ is the response capacity of the i-th represented user in the j-th adjustment period (in kWh), C_j^{LA} is the declared unit price by the load aggregator participating in the electricity peak load assistance service market in the j-th adjustment period (in yuan/kWh), and $C_{i,j}^{user}$ is the peak load price declared by the aggregated user i to the load aggregator in the j-th adjustment period (in yuan/kWh). m is the number of users represented by the load aggregator, and n is the number of adjustment periods for peak load assistance services.

Response capacity is related to the user's load adjustment power and is the integral of the user during the response period:

$$W_{i,j}^{user} = \oint_{T_j} \Delta P_{i,j}^{user}(t)dt \tag{18}$$

where $\Delta P_{i,j}^{user}(t)$ is the load adjustable power reported by the i-th represented user in the j-th adjustment period (in kW), and T_j is the j-th time period.

The calculation method for the load aggregator's adjustable power reporting ΔP_j^{LA} is:

$$\Delta P_j^{LA}(t) = \sum_{i=1}^{m} \Delta P_{i,j}^{user}(t) \tag{19}$$

where ΔP_j^{LA} is the adjustable power reporting by the load aggregator in the j-th adjustment period for participating in the electricity peak load assistance service market (in kW), and m is the number of users represented by the load aggregator.

The probability formula for the bid submitted by the load aggregator to the grid operator and the success rate of the bid is as follows:

$$p_{LA} = \left(\frac{1}{2} - \frac{1}{\pi}\arctan(C_{LA} - \overline{C_{LA}})\right) \times 100\% \tag{20}$$

where p_{LA} is the probability of bid success for the load aggregator, and $\overline{C_{LA}}$ is the bid when the success rate is 50% (in yuan).

The optimization objective function for maximizing the expected profit of the load aggregator is:

$$\max W_{LA,\exp} = F_{LA} \times p_{LA} \tag{21}$$

2) Constraints

The bid submitted by the load aggregator to the grid operator is higher than the bid submitted by participating users to the load aggregator, and the total response power of the aggregator is greater than 0：

$$C_j^{LA} > C_{i,j}^{user} \tag{22}$$

$$W_j^{LA} > 0 \tag{23}$$

where C_j^{LA} is the unit price declared by the load aggregator participating in the electricity peak load assistance service market in the j-th adjustment period (in yuan/kW), $C_{i,j}^{user}$ is the incentive unit price provided by the load aggregator to users in the j-th adjustment period (in yuan/kW), and W_j^{LA} is the response capacity of the load aggregator in the j-th period.

C. Market Process for Optimized Control of Flexible Load Groups.

As the entity responsible for dispatching source and load resources to achieve supply-demand balance, the grid operator aims to minimize the total control cost while adhering to the principle of optimizing the overall social welfare. Under this objective, bilateral competition is organized between source-side units and flexible load resources. The efficient matching of peak demand and supply is realized through unified clearing, taking into account the interests of both load aggregators and source-side units.

1) Optimization Objectives

The goal of the grid operator is to minimize the total regulation cost of source-side units and load resources in grid regulation. The formula is as follows:

$$\min W_{EGO} = W_{LA} + W_{GE} \tag{24}$$

$$W_{LA} = \sum_{j=1}^{n} \int_{t_0}^{t_1} x_{LA,j} C_{LA,j}(t) \Delta P_j^{LA}(t) dt \tag{25}$$

$$W_{GE} = \sum_{j=1}^{n} \int_{t_0}^{t_1} x_{GE,j} C_{GE,j}(t) \Delta P_j^{GE}(t) dt \tag{26}$$

where W_{EGO} is the comprehensive cost of the grid operator's electricity peak load assistance service (in yuan), W_{LA} is the subsidy expenditure of the grid operator to load aggregators for peak load assistance (in yuan), W_{GE} is the subsidy expenditure of the grid operator to source-side units for peak load assistance (in yuan), $C_{LA,j}(t)$ is the reported regulation unit price by load aggregator j, $\Delta P_j^{LA}(t)$ is the reported regulation power by load aggregator j (in kW), $C_{GE,j}(t)$ is the reported regulation unit price by source-side unit j, $\Delta P_j^{GE}(t)$ is the reported regulation power by source-side unit j (in kW), $x_{LA,j}$ and $x_{GE,j}$ are the bidding results for load aggregator j and source-side unit j respectively (1 indicates a successful bid, 0 indicates an unsuccessful bid), and t_0 and t_1 are the start and end times of the peak load period (in min).

2) Constraints

Validity constraint on the reported power of source-side units and load aggregation businesses:

$$\begin{cases} \Delta P_j^{LA}(t) > 0 \\ \Delta P_j^{GE}(t) > 0 \end{cases} \tag{27}$$

where $\Delta P_j^{GE}(t)$ is the reported adjustment power of source-side unit j (kW), and $\Delta P_j^{LA}(t)$ is the reported adjustment power of load aggregation business j(kW).

IV. CASE STUDY

A. Case Setup

To validate the effectiveness of the proposed model in this paper, the case study system adopts the IEEE Standard 14-node model. The case scenario is set for a day from 13:00 to 15:00. Due to weather conditions, the output of renewable energy decreases by 12.3 MW during this period. To compensate for this power supply gap, a day-ahead peak-load assistance service market is organized from 13:00 to 15:00 to call upon the regulation resources on the "source" and "load" sides.

In Section B of this part, User 9, represented by Load Aggregator LA2, is selected, and an optimization case considering satisfaction and bid success rate is presented.

In Section C, Load Aggregator LA2 is chosen, and a case considering user interests and bid success rate for the load aggregator's pricing optimization is presented.

In Section D, a case considering source-load coordination for the market clearing of the power grid operator is set.

B. Optimization of User Quantity-Price Response Strategy

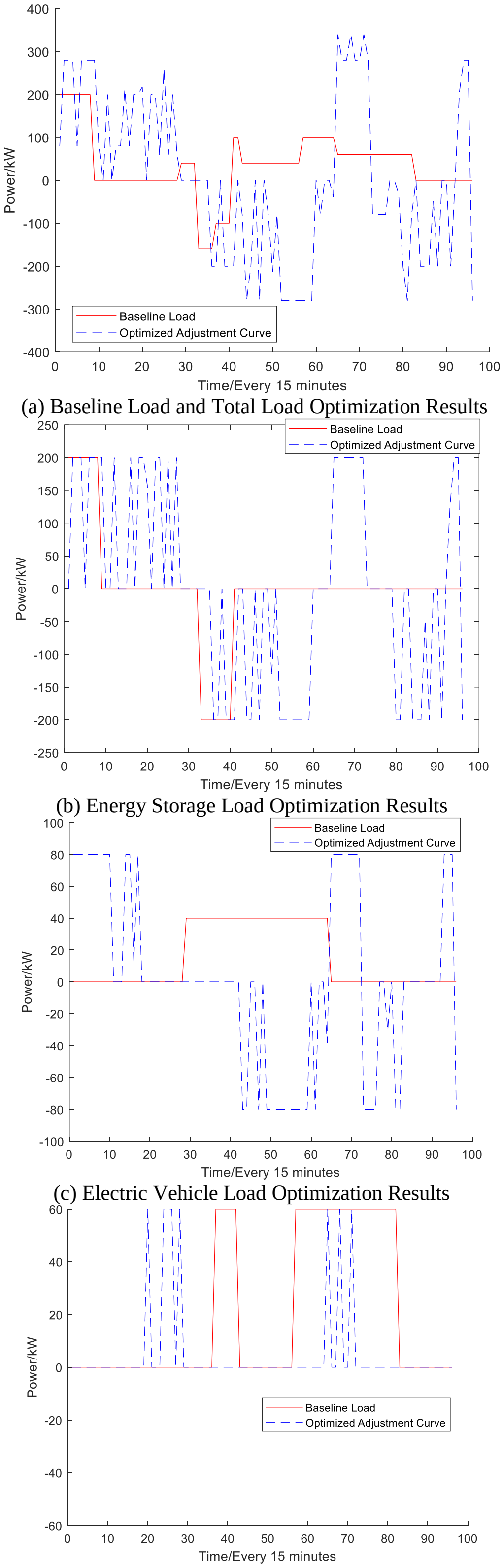
Selected for the case study is electric user 9 under the load aggregator LA2. The flexible load resources of this electric user include energy storage, electric vehicle, and air conditioning. The specific parameters and initial operating state of the load devices are set as shown in Table Ⅰ. The user adopts time-of-use electricity prices, as shown in Table Ⅱ. The baseline load curve of this user is depicted in Figure 2.

TABLE I. FLEXIBLE LOAD PARAMETERS AND INITIAL OPERATING STATE OF A USER

Load Types	Air Conditioner	Electric Vehicle	Energy Storage
Quantity	60	30	40
Parameter Configuration	Rated Power P_{TCL} : 1kW	Rated Power P_{EV} :4kW Rated Capacity C_{EV} : 30kWh	Rated Power P_{ES} ： 5kW Rated Capacity C_{ES} :60kWh
Initial State Setting	Initial Temperature：26-28℃	SOC：0-50%	SOC：0-50%

TABLE II. TIME-OF-USE ELECTRICITY PRICE TABLE FOR USERS

Time Period	Time Type	Electricity Price (yuan/kWh)
0：00-7：00	Valley Period	0.33
7：00-8：30	Off-peak Period	0.71
8：30-16：00	Peak Period	1.18
16：00-18：00	Off-peak Period	0.71
18：00-23：00	Peak Period	1.18
23：00-0：00	Valley Period	0.33



(a) Baseline Load and Total Load Optimization Results

(b) Energy Storage Load Optimization Results

(c) Electric Vehicle Load Optimization Results

(d) Air Conditioning Load Optimization Results

Fig. 2. Baseline Load and Flexible Load Optimization Results.

Applying the user quantity and price optimization model, as presented in Section A of Ⅲ part in this article, to optimize market behavior decisions for this user.

1) Optimization results of user quantity and price bidding

The optimization calculations are performed for each day, and the results of the optimization solution are shown in Table III.

TABLE III. USER QUANTITY-PRICE OPTIMIZATION RESULTS TRANSLATION

	Energy Storage	**Electric Vehicle**	**Air Conditioner**
Quoted Price(yuan/kWh)	0.8	0.8	0.8
Reported Quantity(kW)	200	120	22.5

When the user's bid is 0.8 yuan/kWh, the corresponding load adjustment is 342.5 kW. At this point, the user's participation in the peak shaving market is optimal in terms of combined expected income and comfort, resulting in an incentive fee of 548 yuan.

2) Optimization Results of User's Flexible Load Adjustment Power

As shown in Figure 2(a), the user's total load during the adjustment period has an average reduction of 342.5 kW.

In Figure 2(b), the energy storage load, incentivized by market rewards, shifts the discharge period from the morning to the peak adjustment period. It adjusts according to its maximum adjustable capacity, resulting in an average power reduction of 200 kW.

In Figure 2(c), the electric vehicle switches from charging to discharging during the adjustment period, with an average power reduction of 120 kW.

In Figure 2(d), the air conditioning load reduces its power during the adjustment period, with an average reduction of 22.5 kW.

This case study provides the optimal quantity-price strategy for a single user. Through load data analysis, it verifies the feasibility of the user quantity-price response algorithm that considers satisfaction and bid success rate.

C. Optimization of Load Aggregator Quantity-Price Response Strategy

The number of users represented by Load Aggregator LA2 at Node 2 is set to 10. Table Ⅳ displays the bid and quantity data for the adjustable power of these 10 users represented by Load Aggregator LA2 during the response period. Utilizing the load aggregator pricing strategy optimization model proposed in Section B of Ⅲ part, which takes into account user benefits and bid success rate, we simulate market behavior optimization decisions for LA2.

TABLE IV. LOAD AGGREGATOR LA2'S USER-AGENT ADJUSTMENT PERIOD QUOTATION AND FINAL OPTIMIZATION RESULTS

Users	**Quoted Price (yuan/kWh)**	**Reported Quantity (kW)**	**Bid Awarded**
User 1	0.57	353	√
User 2	1.62	313	×
User 3	0.6	648	√
User 4	0.53	612	√
User 5	1.69	258	×
User 6	1.0	285	√
User 7	1.71	353	×
User 8	1.72	53	×
User 9	0.8	342.5	√
User 10	0.6	69	√

Table Ⅳ also lists the results of the load aggregator's quantity and price optimization calculation. As shown in Table Ⅳ, Load Aggregator LA2 achieves the highest expected revenue when users 1, 3, 4, 6, 9, and 10 are awarded. At this point, Load Aggregator LA2 quotes the grid at 1.2 yuan/kWh, with a quantity of 2.3095MW for the total awarded capacity to users. The total revenue for Load Aggregator LA2 is 5542.8 yuan, of which 3029.5 yuan is allocated for incentive payments to awarded users, resulting in a net profit of 2513.3 yuan for Load Aggregator LA2.

Through simulated calculations of the load aggregator's pricing and quantity optimization strategy, this case study validates the feasibility of the proposed load aggregator strategy model. It also demonstrates the profit potential for the load aggregator.

D. Grid Operator Source-Load Coordination Clearance

A total of 8 load aggregators and 2 power plants participate in the peak-shaving market with quantity and price declarations. The quantity and price declarations of each load aggregator are shown in Table Ⅴ, and the quantity and price declarations of each power plant are shown in Table Ⅵ.

TABLE V. LOAD AGGREGATOR PRICE AND QUANTITY DECLARATIONS

Load Aggregator	Quoted Price (yuan/kWh)	Reported Quantity (kW)
LA1	0.99	8.68
LA2	1.2	2.3095
LA3	1.13	3.04
LA4	2.57	23.12
LA5	0.66	2.84
LA6	1.04	7.3
LA7	0.8	1.85
LA8	0.87	4.5

TABLE VI. GENERATOR PRICE AND QUANTITY DECLARATIONS

Generating Unit	Quoted Price (yuan/kWh)	Reported Quantity (kW)
G1	1.01	9.88
G2	0.82	3.99

TABLE VII. OPTIMIZATION RESULTS OF THE GRID OPERATOR'S MARKET CLEARANCE

Node	Increase Output/Reduce Load (MW)
G2	3.99
LA5	2.84
LA7	1.85
LA8	3.62

The optimization solution was obtained using the grid operator's market clearing model proposed in Section C of the Ⅲ part. It was found that the load aggregators LA5, LA7, and LA8 won the bids. LA5 reduced its load by 2.84MW, LA7 reduced its load by 1.85MW, and LA8 reduced its load by 3.62MW. The generator G2 won the bid, and its output increased by 3.99MW. The grid operator called upon adjustable resources from load aggregators and generators, totaling 12.30MW. The incentive payment by the grid operator amounted to 21,082 yuan. The optimization clearing results are shown in Table Ⅶ.

This case study developed an optimal clearing algorithm for the grid side and validated the clearing model. The results indicate that the proposed algorithm performs exceptionally well in terms of source-load coordination.

V. CONCLUSION

To transform potential regulation resources into practically usable system regulation resources, this work designs a three-layer flexible load aggregation and control framework comprising users, load aggregators, and grid operators. The key conclusions are as follows:

At the user level, a comprehensive consideration of factors such as income, comfort, and bid success rate is employed for electricity strategy decision-making. Users engage load aggregators in load adjustment with quantity and price quotations. Load aggregators, based on agent user quantity and price quotations, make decisions on bid quantity and price strategy towards grid operators, considering bid success rate and aiming to maximize expected income. The grid operator, with the premise of secure and economic operation, minimizes costs while invoking regulation resources on both the source and load sides. Simulations in the case study address the supply-demand gap caused by intermittent output drops in new energy sources. The organization of the day-ahead electricity peak shaving service market scenario enables the utilization of source and load regulation resources. Simulation results indicate that through the multi-layered aggregation and control framework, optimal utilization of adjustable "source" and "load" resources is achievable, ensuring the safe and economic operation of the power system.

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