Multi-energy Coordinated Dispatch of Integrated Transportation Hub During Peak-Period Transactions

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Abstract. The integrated transportation hub is the intersection of the transportation network lines of multiple modes of transportation, and is a whole composed of a variety of fixed devices and mobile devices. With the sharp increase in electricity load and insufficient energy supply, the production and use of electricity has been seriously affected. In order to solve the problem of imbalance between supply and demand during peak load hours, in the gradually opening user-side market, the integrated transportation hub participates in the special transaction of peak demand response as a market entity, and controls the end users under its jurisdiction to reduce the controllable load and obtain compensation costs by signing a contract. This paper first defines the integrated transportation hub considering the flexible load response, and analyzes the function of the integrated transportation hub in the power trading market from the two aspects of market and technology. On this basis, the adjustable potential of various terminal flexible loads of integrated transportation hubs is analyzed and modeled. Finally, the process of the integrated transportation hub's participation in the spike demand response special transaction is analyzed, and the market clearance model for the integrated transportation hub to participate in the spike transaction special session is constructed with the goal of maximizing social welfare, optimizing the transaction price and response amount of the market entity, and realizing the peak load reduction of the power system.

Keywords: Integrated Transportation Hub · Demand Response · Peak Load Period

1 Introduction

With the adjustment of industrial structure, social and economic development and the improvement of residents' living standards, the demand for electricity on the user side continues to grow; a high proportion of clean energy is connected to the grid, the grid

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load shows obvious seasonality and time period, and the social electricity load shows double peaks in winter and summer characteristic, the problem of peak regulation is becoming more and more obvious.

In view of the shortcomings of the traditional supply-demand balance method, under the support of demand response technology, the load aggregator, as an intermediary institution coordinating large industrial users, general industrial and commercial users, residential users and power grid dispatching and trading centers [1], can integrate load resources through professional technical means and participate in the medium and long-term market or demand response market. Taking the implementation measures for power demand response in a province as an example, it is clear that the participants in the power demand response market are direct demand users and load aggregators. Aggregate and disperse small and medium-sized adjustable resources to participate in electricity market transactions, and jointly reduce the load during peak hours and promote clean energy consumption through market-oriented means of demand response; Guide users to transfer noon/evening peak power consumption, which can effectively reduce peak load.

As a passenger and cargo transshipment center connecting a variety of modes of transportation and radiating a certain area, the comprehensive transportation hub builds a convenient, safe and efficient comprehensive transportation system with intensive use of resources, energy conservation and environmental protection, which is of strategic significance for supporting national economic and social development, facilitating the travel of the broad masses of the people, and enhancing national competitiveness. Compared with traditional energy storage power supply, the integrated transportation junction has a variety of adjustable loads, fast response speed and strong climbing ability. A large number of decentralized end users form a flexible energy storage system through the control of load aggregators, so as to integrate the transportation hub, which is a stakeholder to participate in the power trading market, and output power to the power grid to obtain market benefits [2].

Based on the above, this paper proposes a peak transaction clearing model based on integrated transportation junctions. First of all, the comprehensive transportation hub is defined, and from the two aspects of market and technology, the function of the integrated transportation hub in the electricity market is studied to be different from other market entities, and its responsibilities in power trading are clarified. Then, the adjustable potential analysis of various end-user loads at the integrated transportation hub is performed; Finally, the process of the integrated transportation hub's participation in the peak demand response special transaction is analyzed, and on this basis, with the goal of maximizing social welfare, the market clearance model of the integrated transportation hub participating in the peak transaction is constructed, the transaction price and response electricity of the market entities are optimized, and the peak load reduction of the power system is realized.

2 Definition of Integrated Transportation Hub with Demand Response

2.1 Basic Concepts

The integrated transportation hub is a comprehensive transportation and travel service place integrating buses, taxis, long-distance passenger transport, subways and other means of transportation, and is an area with a high degree of distribution of people and traffic, as well as an integrated energy system. It is mainly composed of energy supply networks (such as power supply, gas supply, cooling / heat supply and other networks), energy exchange links (such as CCHP units, generator sets, boilers, air conditioners, heat pumps, etc.), energy storage links (power storage, gas storage, heat storage, cold storage, etc.), terminal integrated energy supply units (such as microgrids) and a large number of end users [3].

The integrated transportation hub refers to the market transaction contract for the market transaction contract of the integrated transportation hub under its jurisdiction that meets the requirements by aggregating the dispersed end users of small and medium-sized flexible resources with load regulation potential, and arranging the charging and discharging plan of the terminal equipment under its jurisdiction by aggregating the dispersed end users of small and medium-sized capacity flexible resources with load regulation potential. The integrated transportation hub shall have the ability to obtain the adjustable capacity of the end-user equipment of the integrated transportation hub under its jurisdiction, the longest and shortest continuous charge and discharge time and other physical parameters, and meet the technical support means of controllable load aggregation and its charge and discharge control.

2.2 Features of the Electricity Market

Under the background of the "plan plus market" dual-track operation [4], power users are divided into non-market-oriented users and market-oriented users, of which non-market-oriented users are mainly residential users who cannot participate in electricity market transactions, and the load aggregator purchases the planned electricity on behalf of the operator, and settles the electricity fee according to the on-grid benchmark electricity price; Market-oriented users are mainly large-scale industrial users and general industrial and commercial users, who can participate in the auction transaction of the electricity market and settle according to the clearing price.

Usually, the electricity trading center will organize the electricity wholesale market and the electricity retail market in the electricity market on time according to the rules of the electricity market, and large industrial users can directly participate in the wholesale market to purchase electricity, or participate in the power purchase transaction represented by the load aggregator, while the general industrial and commercial users must purchase electricity through the load aggregator in the retail market.

In the electricity wholesale market, power trading activities carried out by power generation and integrated transportation hubs through market-oriented methods include medium- and long-term monthly electric energy market transactions, spot electric energy market transactions, and special peak demand response transactions unique to some regions.

Among them, the peak demand response special transaction is the power trading center predicts the next day's power supply and demand balance and determines whether to start the power transaction after the end of the medium and long-term electric energy market, and the integrated transportation hub can participate in the auction and provide interruptible end user load capacity and transferable load capacity as agreed, cut and suspend the electricity demand during the peak period of the power system power supply load, or transfer the peak time electricity demand to the low time of the whole society's electricity demand, and obtain response compensation.

In the electricity retail market, integrated transportation hubs act as electricity sales companies to power users or purchase demand response resources from power users. First, the integrated transportation hub signs demand response agency agreements and electricity sales contracts with end users through bilateral negotiations; Then, on the day of the implementation day, the integrated transportation hub provides power supply services for users, organizes and supervises the neutralization of end users to adjust the load through the load management system, and performs the response duties; Finally, the integrated transportation hub collects the electricity sales fee according to the electricity sales contract and pays the compensation fee to the user according to the demand response agency agreement.

2.3 Technical Features

On the day of operation of the transaction result, under the supervision of the power dispatching center, each market entity will generate and use electricity according to the transaction result. Among them, the centralized control method is generally adopted for demand response resources, that is, the power dispatching center issues dispatching instructions to each load aggregator on the operation day, and then each load aggregator uniformly dispatches and controls the controllable load controlled by itself. Therefore, in order to dispatch and control all kinds of adjustable loads at any time, the integrated transportation hub needs to install a real-time monitoring system of intelligent terminals on the user side, which can monitor the changes in grid voltage and frequency at any time, and make load adjustment according to the power changes of the power grid and the system control instructions.

In the actual operation of the power system, the aggregation and management system of the integrated transportation hub can use the ubiquitous Internet of Things, based on network situation awareness, edge computing and cloud edge integrated control [5], to assist users to achieve metering transformation, collect the user's power, temperature, start-stop control signal, demand response willingness and other information, tap and evaluate the demand response potential contained in the information, and upload the summary information to the power trading center. At the same time, the dynamic optimization control strategy is adopted to realize the real-time optimization of user energy consumption and reduce the energy consumption of electrical equipment. After signing the demand response agreement, the response requirements of the power system are issued to the power users, and the users are helped to perform the response to achieve peak migration and valley filling.

3 Analysis of Demand Response Potential of the Transportation Hub

The integrated transportation hub covers three kinds of loads: cooling, heating and electricity: the electric load is provided by the CHP and the power grid, and the excess electricity is sold to the higher-level power grid; The cooling load is provided by absorption chillers and electric chillers; The heat load is supplied by a combination of CHP and gas-fired boilers. Most of the terminal loads are regarded as constant, but in the integrated transportation hub system, the cold, hot and point loads have good flexible and adjustable characteristics, and through the implementation of demand response, the peak-to-valley difference can be effectively reduced, and the system operation and investment costs can be reduced.

3.1 Flexible Loads

Cooling Load. For the air conditioning system, its load size is related to the outside temperature and the room temperature that needs to be maintained, under the premise of ensuring the user's human comfort, the air conditioning load is adjusted by changing the air conditioning temperature, that is, it has flexible control capabilities.

Assuming that the temperature control equipment in the building has been in a stable operating state, that is, the temperature control assumes that the temperature control equipment in the building has been in a stable operating state, that is, the cooling capacity of the temperature control equipment matches the cooling consumption of the building, based on the basic parameters of the building heating area and the average floor height, according to the current indoor temperature and the maximum temperature allowed by the user, the temperature control equipment can reduce the active power. When the duration is determined, the maximum reduction of the active power can be obtained:

$$P^1_{DR,decreased} \times t^1_{DR} \times EER = c \times S \times H \times \rho \times (T_{\lim it} - T_{set}) \tag{1}$$

wherein: $P^1_{DR,decreased}$ is the active power that can be cut by the temperature control equipment; t^1_{DR} is the duration of load reduction; *EER* for refrigeration energy efficiency ratio for temperature control equipment; t^1_{DR} refrigeration temperature set for the user; T_{limit} is the highest temperature that a building user can tolerate, which is higher than the refrigeration temperature set by the user.

Heating Load. This article assumes that in order to save electricity costs, general industrial and commercial users use energy-saving mode for the use of lighting equipment, that is, the lighting load is already in its lowest load state, and the adjustable potential is small and negligible.

Assuming that the temperature control equipment is already in a stable operating state, that is, the equipment heat production and building heat consumption match, based on the basic parameters of the building heating area and the average floor height, according to the current indoor temperature and the minimum temperature allowed by the user, the active power of the temperature control equipment can be reduced. When the duration is determined, the maximum available active power reduction is:

$$P^{1}_{DR,decreased} \times t^{1}_{DR} \times COP = c \times S \times H \times \rho \times (T_{set} - T_{\lim it}) \tag{2}$$

wherein: $P^{1}_{DR,decreased}$ is the active power that can be cut by the temperature control device; t^{1}_{DR} for the duration of the cut; COP is the heating energy efficiency ratio of temperature control equipment; c is the specific heat capacity of the air, generally the constant pressure specific heat capacity of the air when the temperature is 300K, the value is 1.005kJ/(kg*K); S is the heating area of the building; H is the average floor height of the building; ρ is the density of air, generally select the density of dry air at a temperature of 300K, the value is 1.177kg/m3; T_{set} the heating temperature set for the user; T_{limit} is the minimum temperature allowed by the user, which is lower than the heating temperature set by the user.

3.2 Traffic Loads

Traffic loads, typically electric vehicles and energy storage. However, the cost of energy storage configuration is large, and this paper mainly considers electric vehicles in the integrated transportation hub.

The usable capacity of single electric vehicles is limited, and the capacity of cluster electric vehicles is very considerable. Taking the 110,000 electric vehicles in Hunan Province as an example, according to the average configuration of 40kWh of energy storage batteries per electric vehicle, the mobile energy storage capacity of the province is about equal to 36 Hunan power grid energy storage power stations, which contains huge peak regulation potential [6].

Compared with traditional energy storage power sources, electric vehicles are fast response, strong climbing ability, and 90–95% of the time idle in public parking lots, office buildings and residential areas. Cluster electric vehicles form a mobile energy storage system through the control of load aggregators, and their grid-connected nodes change dynamically at different times, and the grid-connected power state (power generation power or load power) is dynamically switched through the bidirectional converter of the supply facility to realize the two-way interaction between the energy in the electric vehicle and the power system. Electric vehicles are moved to meet their own travel needs, charged as a load, and discharged as a power source to the grid [7].

The integrated transportation hub collects the travel and power information of electric vehicles located in the same area, including activity trajectory, travel location, power consumption, etc., and integrates this information through the energy management center, and then combines vehicle-to-grid (V2G) technology to regulate dispersed electric vehicle users, as shown in Fig. 1:

The usable capacity of an electric vehicle is equivalent to the power range output to the grid, i.e. by equipping the loads that can be increased with the amount of power generation that can be reduced, resulting in a usable down-regulation power range; By equating discharge or reduced charging to an increased amount of power generation, a usable upregulation power range is generated. Based on the charge and discharge

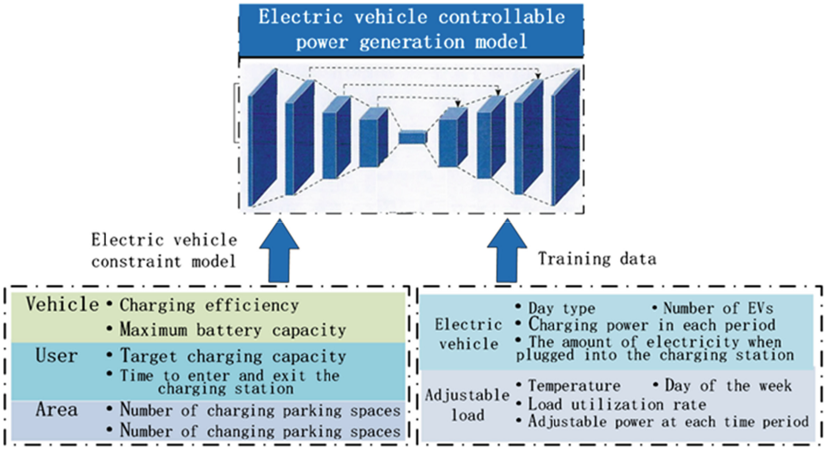

Fig. 1. Electric vehicle load perception mode

boundary between the previous discussions, the usable capacity of the electric vehicle at each moment is as:

$$\Delta\overline{p}^e_{n,t} = \frac{(S^e_{n,t} - \underline{S}^e_{n,t+1})Q^e_E}{\Delta t} \tag{3}$$

$$\Delta\underline{P}^e_{n,t} = -\frac{(\overline{S}^e_{n,t+1} - S^e_{n,t})Q^e_E}{\Delta T} \tag{4}$$

In the formula, $\Delta\overline{p}^e_{n,t}$ and $\Delta\underline{P}^e_{n,t}$ represent the up-regulation and down-regulation of the usable capacity of the electric vehicle, $\overline{S}^e_{n,t+1}$ and $\underline{S}^e_{n,t+1}$ are the charging and discharging boundaries, and $S^e_{n,t}$ represents the charge state of the electric vehicle t at the n node at any time.

4 Integrated Transportation Hub Participates in the Special Transaction Process During Peak Periods

The distribution characteristics of peak load are similar to the electricity consumption habits of power users, and their occurrence time is mainly concentrated in the afternoon peak period and evening peak period of user electricity consumption. If the flexible load of industrial and commercial users of the integrated transportation hub is aggregated through the load aggregator, and the user is guided to transfer the electricity consumption of the noon/evening peak, the peak load can be effectively reduced.

The peak demand response session is a special session for the peak load period, using the user's side of the unilateral centralized auction transaction, unified clearing algorithm for clearance, with "spread priority, time priority, environmental protection priority" as the clearing calculation principle [8].

4.1 Special Launch Conditions and Transaction Targets

The power trading center predicts the load curve $p(t)$ of the next day, and determines whether to start the peak demand response session in combination with the peak over-limit δ and over-limit duration threshold ε. Using the peak load exceeding the limit value to determine whether there is a starting period so that the load curve $p(t)$ is greater than δ, that is, a peak period occurs, and the determination method is as follows:

$$p(t_1 - 1) \leqslant \delta, p(t_1 + 1) > \delta \tag{5}$$

$$p(t_2 - 1) > \delta, p(t_2 + 1) \leqslant \delta \tag{6}$$

When the period (t_1, t_2) satisfies the formulas (2) and (2), it can be determined to be a peak period.

The power trading center can set the threshold ε for the over-limit duration according to the opening degree of the special session and the trading time scale, and can determine whether the peak period meets the minimum limit of the opening duration of the special session:

$$t_2 - t_1 \geqslant \varepsilon \tag{7}$$

When the time period (t_1, t_2) satisfies the formula (3), the peak period meets the minimum limit of the opening time of the special session, and the power trading center can start the special session of peak demand response and announce the special transaction target.

The special transaction targets for peak demand response include the response demand Q_{DR} during the transaction period and the upper $\pi_{ds,max}$ and lower limit $\pi_{ds,min}$ of the compensation electricity price. If the power trading center takes the period (t_1, t_2) as a special trading period, the response demand can be calculated:

$$Q_{DR} = \int_{t_1}^{t_2} p(t)dt \tag{8}$$

At 8:00 a few days ago, the Electric Power Trading Center announced the trading information of the special trading session, that is, the trading session, the response demand and the upper and lower limits of the compensation electricity price, and organized the responding subjects to participate in the special trading.

4.2 Unilateral Bidding on the Demand Side

The integrated transportation hub declares the compensatory electricity price that can respond to the capacity and the expectation through the power trading center platform.

4.3 Special Clearing

The electric power trading center sorts according to the declared price of electric vehicle load aggregators from low to high, the declared value of responsive capacity from high to low, and the declaration time from early to late, until the responsive capacity reaches or exceeds the response demand, forming an unconstrained transaction As a result, the clearing price is the declared price of the winning bidder. The electric power trading center calculates the special declaration information to form the unconstrained trading result of unilateral centralized bidding.

4.4 Safety Check

Submit to the power dispatching agency for safety verification, and form a constrained transaction result.

Among them, the compensation point price constraint:

$$\pi_{ds,min} \leqslant \pi_{ds,bd,k} \leqslant \pi_{ds,max} \tag{9}$$

5 Market Clearance

5.1 Objective Function

The power grid company predicts the supply gap curve $P_{d,gap}(t)$ of the next day on $d-1$, and sends an invitation to the demand response resource pool through the power trading center:

$$P_{d,gap}(t) = \max\left\{\left(P_{d,l}(t) - P_{d,s}(t) - P_{d,f}(t) - P_{d,g}(t) - P_{d,t,h,max}\right), 0\right\} \tag{10}$$

In the formula: $P_{d,gap}(t)$ is the supply gap curve of the power system on the d day; $P_{d,l}(t)$ is the load curve on the d day; $P_{d,s}(t)$ (t) is the first The hydropower output curve of day d; $P_{d,f}(t)$ is the wind power output curve of the d day; $P_{d,g}(t)$ is the photovoltaic output curve of the d day; $P_{d,t,h,max}$ is the maximum technical output of the thermal power unit on the d day, which is a constant.

The invited load aggregators can query their baseline load standard $P_{l,base}$ through the power trading center and choose whether to be invited. According to the invitation situation, the adjustable load of the resource pool on the d day can be calculated by the following formula:

$$P_d = \sum_{l=1}^{L^*} l^* P_{1,mon},\ l^* \in L^* \tag{11}$$

In the formula: P_d represents the adjustable load of the demand response resource library on the d day; l^* represents the invitation status of the l th load aggregator, if it is invited, $l^* = 1$, if it is rejected, then $l^* = 0$.

When there is a period (t_1, t_2) such that $P_{d,gap}(t) > P_d$, the power trading center organizes bidding and listing transactions, and the load aggregators who still have spare capacity after being invited and the load aggregators who failed to delist in the previous stage can participate. According to the order of the declared electricity price from low to high, the power trading center sorts the various levels of the load-electricity price curve declared by the above load aggregators, and also builds a clearing model with the objective function of maximizing social welfare. The objective function can be expressed as follows:

$$\max F(P) = \sum_{l=1}^{L**} \int_{0}^{P_{l,win}} [r_l - \lambda_l(P_l)]dP_l \tag{12}$$

$$L^{**} = L^{-} + \sum_{l=1}^{L*} l^{*} \tag{13}$$

In the formula: L^{**} is the total number of load aggregators that can participate in the bidding and listing transaction; $P_{l,win}$ is the winning load of the l load aggregators.

5.2 Constraints

Supply and demand balance constraints

$$P_d + \sum_{l=1}^{L**} \left[P_{l,win}(t)\right] = P_{d,gap}(t), t \in (t_1, t_2) \tag{14}$$

integrated transportation hubs can regulate potential constraints

$$\begin{cases} 0 < P_{l,win}(t) + P_{l,mon} \leqslant P_{l,pub}, l \in L* \\ 0 < P_{l,win}(t) \leqslant P_{l,pub}, l \in L^{-1} \end{cases} \tag{15}$$

For the load aggregator in the R library, the adjustable load that participated in the pricing listing in the previous stage and the bidding in this stage should be less than its public value.

For the load aggregator in the R^{-} library, the adjustable load of the bid winning bid should be less than its public value.

Genset down ramp rate constraint

$$-v_{n*,down,\max} \leqslant P'_{n*}(t) \leqslant 0, n* \in N*, t \in (t_1, t_2) \tag{16}$$

In the formula: $P'_{n*}(t)$ is the derivative of the output function of the unit $n*$ in the time period (t_1, t_2).

5.3 Compensation Fee Settlement

As a market entity, load aggregators may announce or declare their adjustable loads and compensatory electricity prices according to their own wishes。However, in the actual transaction process, there may be the following phenomenon: in the information publicity stage, the integrated transportation hub declares its adjustable load and compensated electricity price according to its actual response cost; According to the market publicity information in the previous stage, the monthly pricing listing is deliberately dropped; In the recent auction listing stage, the strategic quotation method is adopted to raise the price of electricity and increase its own income. In view of this phenomenon, the strategic quotation of load aggregators can be suppressed through a reasonable and effective VCG allocation mechanism.

The settlement process of the day-ahead bidding listing special transaction is shown in Fig. 2:

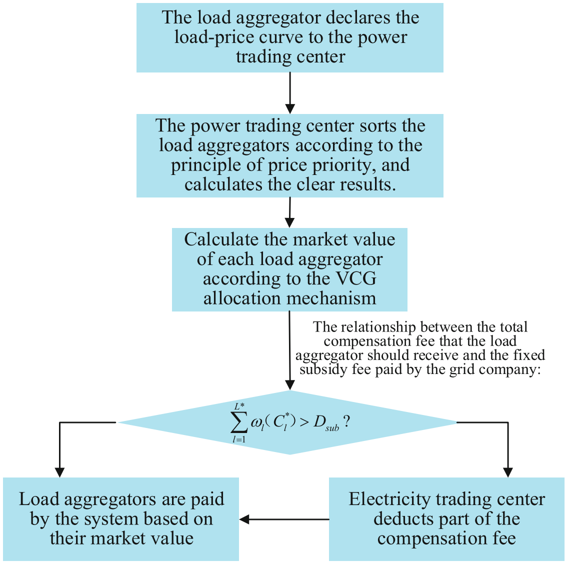

Fig. 2. Peak demand response special transaction process.

6 Conclusion

The peaking potential of integrated transportation hubs is considerable, providing dispatchable capacity for the power system and reducing peak loads. This paper first defines the integrated transportation junction, and studies the function of the integrated transportation hub in the electricity market that is different from other market players from both market and technical aspects, and clarifies its responsibilities in power trading. Then, the adjustable potential analysis of various end-user loads at the integrated transportation hub is performed; On this basis, the process of comprehensive transportation hubs participating in the peak demand response special transaction is elaborated, and on this basis, with the goal of maximizing social welfare, the market clearance model of the comprehensive transportation hub participating in the peak transaction is constructed, the transaction price and response electricity of the market entities are optimized, the theoretical feasibility of the comprehensive transportation hub to participate in the power transaction in response to the demand is provided, and the idea is provided for effectively improving the enthusiasm of the integrated transportation hub to participate in the market independently and promoting the peak shaving of the power grid.

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