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Optimal Energy Storage Allocation Strategy by Coordinating Electric Vehicles Participating in Auxiliary Service Market

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ABSTRACT The further liberalization of China's electricity market encourages demand-side entities to participate in electricity market transactions. Electric vehicles (EVs) are developing rapidly and have high regulating potential, and are the main force for demand-side participation in the auxiliary service market. Aiming at the problems of dispatching accuracy and economy in EV participation in auxiliary service market, this paper analyzes the bidding strategy and dispatching scheme of EV-storage participation in auxiliary service market, and proposes EV-storage optimal allocation strategy with the goal of economic optimum. In the process of optimal allocation, based on the market rules of third-party subject participation in auxiliary services, the bidding strategy of EV-storage coordinated EV participation in auxiliary services market considering daily load scale changes is designed, while the conditional value at risk (CVaR) method is used to determine the short-term coordinated energy storage capacity and efficiency storage capacity considering the uncertainty of EV response situation; then, based on the annual EV load scale change, the benefit calculation function is constructed by considering various factors such as auxiliary service market revenue, spread revenue, investment cost and market opportunity cost of EV-storage participation in the auxiliary market. Finally, taking EV aggregation participation in the valley-filling ancillary service market as an example, it is verified that the strategy proposed in this paper can effectively improve the responsiveness of EV participation in the ancillary service market and increase the revenue of electric vehicle aggregator (EVA).

INDEX TERMS EV, energy storage planning, coordinated dispatch of energy storage, ancillary services market, CVaR.

I. INTRODUCTION

With the increasing prominence of global resource and environmental protection issues, the traditional energy flow structure is in urgent need of improvement. The reform of China's electricity market has further promoted the interaction between supply and demand, and encouraged the participation of third-party entities in auxiliary services, which is an important means to promote the consumption of renewable energy and improve energy efficiency in the energy internet era. China's new energy vehicles are developing rapidly, and the number of Electric Vehicles (EVs) is expected to reach 60 million by 2030, and the peak charging load will reach 479 GW [1]. At the same time, EVs participation in the ancillary services market has great potential for development, which is important for promoting a high percentage of renewable energy consumption [2], reducing the cost of ancillary services, and maintaining load stability [3], [4].

Current research on demand-side participation in ancillary service markets is mainly centered on market organization and dispatch operation. EV as a type of mobile energy storage has load regulation capability [5]–[7]. The literature [6]

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considered EV mobile storage to provide primary frequency regulation control; the literature [7] smoothed out grid load fluctuations through the control of EV mobile storage, and the results proved that EV mobile storage has a large regulation potential to realize distribution grid regulation. It can be seen that the current research results mainly verify the feasibility of EV participation in the auxiliary service market from a theoretical point of view. However, with the further liberalization of the demand-side market, the actual dispatching scheme for EVs to participate in the auxiliary service market as a third-party subjects need to be further designed, and the research on the bidding strategy and benefit measurement for EV aggregation participation in the auxiliary service market needs to be carried out urgently. At the same time, how to avoid the market losses caused by the randomness of large-scale EVs and the difficulty of regulation is an important issue to be considered.

Centralized energy storage resources are often used for power regulation with various types of resources using advantages such as good economics and strong regulation capacity [8]–[10]. For example, literature [11] proposed the strategy of battery energy storage to participate in wind power auxiliary service market, which promoted wind power consumption and improved resource utilization efficiency while ensuring market benefits. Therefore, the application of centralized energy storage in EVs load regulation can be considered. Among the results in this area, literature [12] used EVs hybrid energy storage for power regulation, but did not consider the market strategy and long-term optimal allocation scheme of energy storage; literature [13] used electric energy storage configuration to achieve the effect of risky backup, but did not consider the market situation and short-term optimal scheduling method. The existing research results have not yet been discussed in the context of practical applications in terms of market response capacity and market benefits for the participation of energy storage coordinated EVs in auxiliary services [14]–[16]. For the EV-storage participation in the ancillary service market, we have to study the variation of long-term EV response capacity to plan the energy storage construction, and the randomness of short-term EV response to set the optimal bidding strategy.

Scheduling technology and big data technology are key technologies related to the efficiency of aggregated participation in the ancillary services market [17], [18]. In terms of optimal scheduling, literature [19] proposes an EV regulation strategy that integrates response time margin (RTM) and state of charge margin (SOCM) through day-ahead scheduling and intra-day correction; literature [20] proposes a two-sided optimal utilization strategy, and the strategy optimization results have obvious effects. However, these are not designed for the ancillary services market, and do not consider studies that go beyond optimal regulation of capacity or involve precision checks. The literature [21] proposes a power allocation approach based on the state of charge (SOC) of EVs and energy storage to achieve real-time power adjustment, but the strategy does not take advantage of the cost advantage and uniform regulation of centralized energy storage. In terms of data collection and processing, the main approaches are currently statistical-based function processing approaches and capacity prediction models based on artificial intelligence algorithms [20], [22]. Accurate and reliable model construction is beneficial to ensure optimal scheduling effects.

In general, with the scale development of EVs and the continuous maturity of V2G technology, the participation of EVs in grid regulation needs to take into account not only the EV charging and discharging characteristics and grid demand [23], but also the power market demand [24]–[26]. However, in terms of market bidding scheme, there has not yet been a bidding scheme design for joint EV-storage participation in the power market combined with actual engineering; in terms of capacity planning and construction, there has not yet been a study on joint EV-storage optimal dispatching scheme considering the long-term EV response scale change and short-term EV response uncertainty; in terms of benefit calculations, there is no measurement scheme for EV-storage participation in the electricity market that incorporates specific market construction scenarios.

In view of this, this paper first proposes a bidding strategy for centralized energy storage to coordinate EV mobile storage participation in the auxiliary service market based on the current situation of power demand-side market. Then, the short-term response capacity calculation method of EV participation in the auxiliary service market based on least squares support vector machines (LSSVM) and the measurement method of short-term coordinated energy storage capacity demand based on CVaR are proposed. Further, based on the short-term response method of energy storage coordinated EV participation in auxiliary services, the long-term market benefit source and calculation method of auxiliary services are proposed, considering the construction of EV mobile energy storage and centralized energy storage. Finally, the effectiveness of the strategies and methods proposed in this paper is verified by using the example of EV participation in the electricity market in city A.

The remainder of this paper is structured as follows: Section 2 designs the market mechanism for joint EV and storage participation in ancillary services; Section 3 proposes a method for determining the response capacity of EV-storage participation in the ancillary services market; Section 4 proposes the calculation of ancillary services market benefits; Section 5 is a case study; And section 6 is a conclusion.

II. MARKET MECHANISMS

After EV is connected to the grid, it can interact with the grid flexibly like an energy storage device, which is a typical kind of mobile energy storage. It has performance and price differences with centralized energy storage in practical application: centralized energy storage can achieve precise regulation when directly participating in auxiliary service peaking, but it also has higher response cost; EV mobile energy storage is more economical when participating in auxiliary service peaking, but it also has the disadvantage of

TABLE 1. Comparison of EV mobile energy storage and centralized energy storage.

Contrast Items	EV mobile energy storage	centralized energy storage（Lithium-ion batteries）
Investment cost	185-333$/kW[27]	1085-4100$/kW，900-6200$/kWh[27]
Benefit source	EV charge service	Load adjustment and standby service
Control method	User active response	Direct intelligent control
Response speed	Hourly response, daily response	Minute response, hourly response
Response speed	Large, strong uncertainty	Accurate control
Dispatchability	A lot of constraints, considering user requirements	Relatively few constraints
Application scenarios	Peak regulation, renewable energy consumption	Various types of ancillary services

large load fluctuation due to strong uncertainty on the user side. Therefore, EVA considers allocating a certain scale of centralized energy storage for EV mobile energy storage to achieve the unity of reliability and economy.

A. ANALYSIS OF RESOURCE CHARACTERISTICS

In the process of participating in auxiliary services, EV mobile energy storage can produce similar valley filling effect with centralized energy storage resources, but they have differences in investment cost, benefit source, control method, response speed, load volatility, dispatchability and application scenarios. Rational positioning of EV mobile energy storage and centralized energy storage in auxiliary services is necessary to achieve effective coordinated dispatch. Table 1 compares the characteristics of EV mobile energy storage and centralized energy storage, which helps to analyze the positioning of different types of energy storage resources in auxiliary services.

EV mobile storage does not have sufficient ability to provide reliability service to the power system alone due to its randomness and uncertainty; however, at the same time, EV mobile storage has the characteristics of slave quantity, large scale and large regulating potential, which is a typical representative of flexible resources. Therefore, in the process of EV mobile storage participation in auxiliary services, EV mobile storage can be considered as the basic regulating resource and centralized storage as the coordinating supplementary resource, in order to take into account the reliability and economy of EV participation in the power system. Their mutual coordination relationship is shown in figure 1, In the following, "EV" refers to EV mobile energy storage and "energy storage" refers to centralized energy storage for easy understanding.

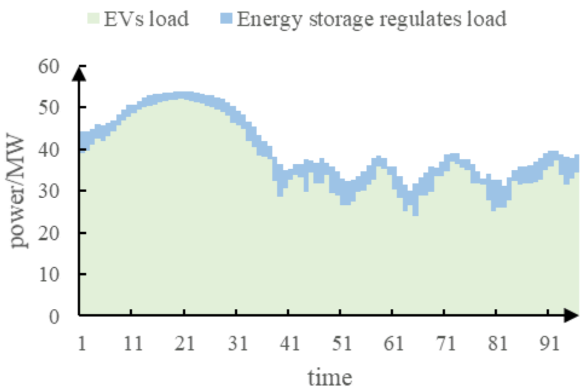

FIGURE 1. Scope and effect of EV - energy storage coordination scheduling.

Accordingly, this paper proposes the market strategy of EV and energy storage resources aggregation for auxiliary services. Firstly, we calculate the aggregated response capacity of EV based on big data technology; then we design the market bidding strategy for EV response capacity and energy storage resources, and set up different bidding schemes considering the demand for energy storage under different EV load scale scenarios; and we calculate the actual response capacity of EV auxiliary service market based on different bidding schemes, and propose the market benefit calculation scheme for EV-energy storage response. Finally, the long-term planning and construction plan of energy storage resources is proposed based on the overall aggregated benefits.

B. BIDDING STRATEGIES FOR EVA TO PARTICIPATE IN THE ANCILLARY SERVICES MARKET

EV participation in the auxiliary service valley filling market requires reporting of valley filling auxiliary service time and capacity. In the actual response process, if the actual response capacity error exceeds a certain range, it will be penalized. For example, when EV participates in valley filling auxiliary service, if the response capacity error is within a certain range, the revenue will be deducted according to the ratio of the response error to the reported capacity, and if it exceeds the range, the response will be regarded as a failure and all revenue will be lost. To avoid the opportunity cost due to response bias and randomness of EV users, we can fill the response bias by real-time dispatch response of energy storage. Therefore, we propose a market strategy and computational framework for energy storage to coordinate EV participation in ancillary services as shown in figure 2.

In the annual EV load change curve, the daily EV load size in different periods has obvious capacity differences, so the energy storage capacity allocated under long-term planning is not necessarily the optimal coordinated energy storage demand for that day. Using CVaR, the daily coordinated EV energy storage demand capacity for participating in auxiliary services can be calculated, and the remaining energy storage can be reported directly to participate in the auxiliary service

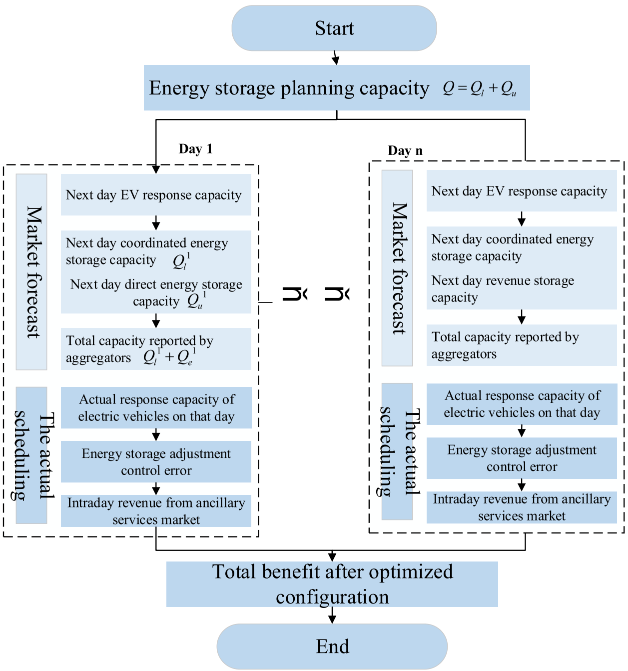

FIGURE 2. **Energy storage coordinates the participation of EVs in ancillary service market strategy.**

market. In the process of calculating the reported capacity curve of the previous day and the actual dispatching of the next day, energy storage plays an important role as a coordinating resource for EV.

The configuration of energy storage devices of different sizes will have different levels of ability to coordinate EV participation in the ancillary services market. For this purpose, two concepts of promised energy storage and efficiency energy storage are defined. Promised energy storage is the coordinated energy storage capacity required to keep the EV load error within the market threshold; efficient energy storage capacity is the coordinated energy storage capacity required to make the EV response error close to zero, and its capacity is calculated as shown in section 2.3.

On the basis of the completion of long-term energy storage planning, consider the difference between short-term EV response load scale and energy storage planning capacity to discuss the bidding strategy in the following three cases:

(1) If the configured energy storage capacity is larger than the benefit energy storage demand capacity on that day, regulate the benefit energy storage capacity resources to coordinate EV participation in auxiliary service market transactions, and the remaining part is reported to the auxiliary service market independently.

(2) If the configured energy storage capacity is lower than the benefit energy storage capacity and higher than the promised energy storage demand capacity, the promised energy storage capacity will be regulated to coordinate the EV to participate in the auxiliary service market transaction, and the remaining part will be reported to the auxiliary service market independently.

TABLE 2. **Market response under different bidding strategies.**

Bidding strategy	Market response capacity of EV	Direct energy storage capacity	Price	Settlement gains and losses
(1)	EV + Settlement gains and losses	Energy storage planning capacity - Settlement gains and losses		Standard revenue
(2)	EV + promised energy storage	Energy storage planning capacity - promised energy storage	Ancillary services market clearing prices	Standard revenue - settlement losses
(3)	EV	Energy storage planning capacity		Standard revenue - settlement losses

(3) If the configured energy storage capacity is lower than the promised energy storage demand capacity, all energy storage resources will be reported to the auxiliary service market directly and independently.

At present, demand-side entities such as EVs have relatively small capacity to participate in ancillary services market, and actually do not participate in the offer, but have the right to priority clearing. Therefore, their market settlement benefits are mainly influenced by both bid volume and settlement losses. The market situation under different bidding strategies are shown in table 2.

According to table 2, the market gains and losses are as follows: (1) benefits come from EV load and directly reported storage capacity with no benefit loss; (2) benefits come from EV load and directly reported storage capacity with benefit loss, and the size of the loss depends on the penalty factor of the market; 3) benefits come from directly reported storage capacity, and EV resources fail to compete successfully. The strategy ensures the market benefits of valley filling auxiliary services while simplifying the dispatch operation as much as possible. Based on this, the EV and energy storage capacity response size measurement is designed in Section 3, and the market benefit calculation model under the strategy is constructed in Section 4.

III. MEASUREMENT OF RESPONSE CAPACITY

A. GENERAL SITUATION OF EVA

The response scale of the EVA's participation in the ancillary services market depends on the EV scale and charging demand in the region, as well as the regulation effect and direct response capability of the energy storage resources that the aggregator has. The specific scale is determined by considering different determination methods for the short term (daily) and long term (annual).

The short-term EVA response size can be accurately predicted by data analysis techniques. In contrast, the long-term

EVA response size can be calculated by using historical short-term response situation data and simulating its distribution using statistical methods [11]–[13].

B. EV RESPONSE CAPACITY

1) SHORT-TERM EV RESPONSE CAPACITY

Demand-side participation in the valley-filling ancillary service is conducted on a daily basis, with transactions conducted at 40 points in time when the market for valley-filling ancillary service is open. In this section, the existing EV load situation is forecasted to derive the daily load response capacity size. At the same time, based on the prediction results, the storage optimization allocation method is set, and the storage is adjusted to the deviation of EV's market response capacity in real time, so as to improve the market performance of EV's response.

In this section, LSSVM is used for typical daily load forecasting in order to achieve a situational analysis of the intra-day EV load [14]. Also, the simulation results of the model are used to study the deviation distribution of EV participation in the ancillary services market as a sample for statistical analysis of the overall deviation distribution, which is used to calculate the size of coordinated energy storage capacity under conditional risk. This section focuses on the key steps of its main algorithm LSSVM.

LSSVM is based on the principle of structural risk minimization to find the optimal w, b, and the optimization problem is as equation (1).

$$min\ \frac{1}{2}w^T w + r\sum_{i=1}^{n}\xi_i^2 \tag{1}$$

where, $r > 0$ is the penalty parameter, and ξ_i is the relaxation variable.

And there are constraints as in equation (2).

$$y\left[w_T \cdot \varphi(x_i) + b\right] = 1 - \xi_i, \quad i = 1, 2, \cdots, n \tag{2}$$

Applying the Lagrange functions to solve the optimization problem:

$$\begin{aligned} L &= \frac{1}{2}w^T \cdot w + r \cdot \frac{1}{2}\sum_{i=1}^{n}\xi_i^2 \\ &\quad - \sum_{i=1}^{n}\alpha_i\left\{y_i\left[w^T \cdot \varphi(x_i) + b\right] - 1 + \xi_i\right\} \end{aligned}$$

$$s.t.\ \begin{cases} w = \sum_{i=1}^{n}\alpha_i y_i \varphi(x_i) \\ \sum_{i=1}^{n}\alpha_i y_i = 0 \\ \alpha_i = r\xi_i \\ y_i\left[w^T \cdot \varphi(x_i) + b\right] - 1 + \xi_i = 0 \end{cases} \tag{3}$$

where, α_i is the Lagrange multiplier vector, and $\alpha_i > 0$, $i = 1, 2, \cdots, n$. The final prediction function can be obtained as shown in Equation (4).

$$f(x) = \sum_{i=1}^{n}\alpha_i K(x, x_i) + b \tag{4}$$

wherein, $K\left(x_i, x_j\right) = \varphi(x_i)^T \varphi\left(x_j\right)$ is the kernel function satisfying the Mercer condition.

2) LONG-TERM EV RESPONSE CAPACITY

Long-term EV response capacity is the sum of short-term EV response capacity within the term. After verifying that the EV response capacity distribution conforms to the normal distribution, the distribution of daily EV charging capacity during the year can be obtained by fitting the normal cumulative distribution function, which is shown in equation (5).

$$F(q) = \frac{1}{\sqrt{2\pi}\sigma}\int_0^q \exp\left(-\frac{(q-\mu)^2}{2\sigma^2}\right) \tag{5}$$

where, q is the size of short-term response capacity; μ and σ are the mean and standard deviation parameters of normal distribution.

Further simulations using the distribution function yield multiple short-term response capacity samples, which can be summed to study the long-term response capacity of EVs.

C. ENERGY STORAGE RESPONSE CAPACITY

CVaR is an improved theory of value-at-risk (VaR) proposed by scholars such as Rockafeller and Uryasev, which reflects the potential loss of a portfolio, and has the characteristics of being simple to calculate and not relying on the assumption of normal distribution of functions [19], and its basic equation is as follows.

$$CVaR_\beta = E\left[f|f \geq VaR_\beta\right] \tag{6}$$

where, f represents portfolio losses; β represents confidence level.

In the actual EV demand response process, there is a difference between the EV expected responsable capacity and the actual EV response capacity. The EV capacity difference is described by VaR, which can be expressed as Equation (7) [28]; the EV capacity difference is described by CVaR, which can be expressed as Equation (8), and can be expressed as Equation (9). Under this energy storage capacity convention, the EV response capacity deviation can be guaranteed to be supplemented at a certain confidence level.

$$f(t, P) = P_t - E_t \tag{7}$$

$$P\left(f(t, P) \leq VaR(p)\right) = 1 - p \tag{8}$$

$$\tilde{F}_\beta(t, P) = a + \frac{1}{m(1-\beta)} \times \sum_{k=1}^{m}\left[f\left(t, P^k\right) - a\right]^+ \tag{9}$$

$$\left[f(t, P) - a\right]^+ = \begin{cases} f(t, P) - a, & f(t, P) > a \\ 0, & f(t, P) \leq a \end{cases} \tag{10}$$

where, $f(t, P)$ is the gap power; P_t is the response power value to be provided at time t; E_t is the peak modulation power of the actual response at time t; p is the confidence level; $\tilde{F}_\beta(t, P)$ is the estimated value of CVaR, namely the energy storage capacity required to coordinate EV; In the case of discrete distribution, m is the number of simulated data; a is the value of VaR; β is the confidence level.

Since there is a boundary for the market efficiency calculation of ancillary services, there is also a threshold for coordinating the energy storage capacity for EV participation in ancillary services. Minimizing the waste of energy storage capacity while satisfying the risk requirement is the optimal storage capacity requirement needed for coordinated dispatch. According to equation (9), equation (11) and equation (12) can be established.

$$E_{\lambda_1,battery} = a + \frac{1}{m \cdot \lambda_1} \sum_{k=1}^{m} \left[f\left(t, P^k\right) - a \right]^+ \quad (11)$$

$$E_{\lambda_2,battery} = a + \frac{1}{m \cdot \lambda_2} \sum_{k=1}^{m} \left[f\left(t, P^k\right) - a \right]^+ \quad (12)$$

where, $E_{\lambda_1,battery}$ is the efficient energy storage capacity; $E_{\lambda_2,battery}$ is the promised energy storage capacity; λ_1 and λ_2 reflect the error range of short-term EV response,λ_1 is the critical value of not being punished by the market and being punished by the market, and λ_2 is the critical value of EV's capacity to participate in the market.

IV. ENERGY STORAGE ALLOCATION MODEL BASED ON MAXIMIZING THE MARKET BENEFITS OF ANCILLARY SERVICES

The benefits of energy storage coordinating EV participation in auxiliary services mainly include: the auxiliary service market benefits generated by EV, and the auxiliary service market benefits generated by energy storage resources. Among them, EV will have a part of benefit loss without the coordination role of energy storage, which is recorded as opportunity loss here; the coordination role of energy storage enables it to obtain this part of benefit, and at the same time, the energy storage resource itself has the ability to participate in the auxiliary service market.

A. BENEFITS OF EV PARTICIPATION IN ANCILLARY SERVICES

After participating in the ancillary service market, EVs can receive compensation for ancillary services. In this paper, we take the north China ancillary service market as an example, and the equation for calculating the size of its 15-minute revenue is shown in (13), and the cumulative revenue for the whole day is shown in equation (14).

$$F_t = K^t \times min\left\{\frac{E_t}{P^t_{base}}, 1\right\} \times min\{E_t, P^t_{base}\} \times t \times A^t_{out} \quad (13)$$

$$W = \sum_{t \in T} F_t \quad (14)$$

where, F_t is the valley filling auxiliary revenue obtained by market entities at time t; K^t is the market coefficient, which is the reciprocal of the average load rate of thermal power units in the provincial power network, which is temporarily set as 1.2 in this paper. min $\left\{\frac{E_t}{P^t_{base}}, 1\right\}$ is the contribution rate of valley filling, E_t is the peak-adjusting power of response at time t; P^t_{base} is the benchmark valley filling power at time t; t is the response time, which is 15 minutes in this paper; A^t_{out} is the market clearing price at time t; W is the total revenue of daily ancillary services; T is the opening session for ancillary services.

Considering that EVs have to pay investment and maintenance costs even without participating in auxiliary services, the incremental investment and maintenance costs of EV participation in auxiliary services are not considered. However, in the process of EV participation in auxiliary services, if the difference between the actual response capacity and the reported response capacity is beyond the market specified range, there is an opportunity loss as in Equation (15).

$$A_{e,t} = \gamma\left(K^t \times E_t \times t \times A^t_{out}\right)$$
$$\begin{cases} \gamma = 0, & a < \lambda_1 \\ \gamma = 1 - \dfrac{E_t}{P^t_{base}}, & \lambda_1 \le a < \lambda_2 \\ \gamma = 1, & a \ge \lambda_2 \end{cases} \quad (15)$$

where, $A_{e,t}$ is the penalty cost at time t; γ is the penalty coefficient; $a = \frac{E_t - P^t_{base}}{E_t}$ is the load deviation rate.

B. BENEFITS OF ENERGY STORAGE

EV mainly participates in the valley filling auxiliary service, and when the actual valley filling load is lower than the reported capacity of the auxiliary service within a certain range, it will give penalty or not settle the revenue. In order to make EV meet the market requirement of the normative error between the actual load and the reported load, energy storage resources need to make timely adjustment. After completing the auxiliary service scheduling, the stored power can be exported during peak hours to obtain the peak-valley tariff difference revenue, and the revenue of energy storage resources participating in each type of market is shown in figure 3.

Where, $E_{b,battery}$ is the total capacity of the energy storage equipment owned by the aggregator; $w_{u,t}$ refers to the income of the energy storage system directly participating in the auxiliary service at time t; $W_{u,f}$ is the peak-valley electricity price income of energy storage resources when they discharge in non-market period; W_u is the total revenue of energy storage participating in the ancillary services market; $w_{l,t}$ is the market income of coordinated energy storage participation in ancillary services; $W_{l,f}$ refers to the peak and valley electricity price income for coordinated energy storage; $w_{l,ev,t}$ is the opportunity loss reduced after coordinating the energy storage assisted EV; W_l is the total benefit of coordinated energy storage.

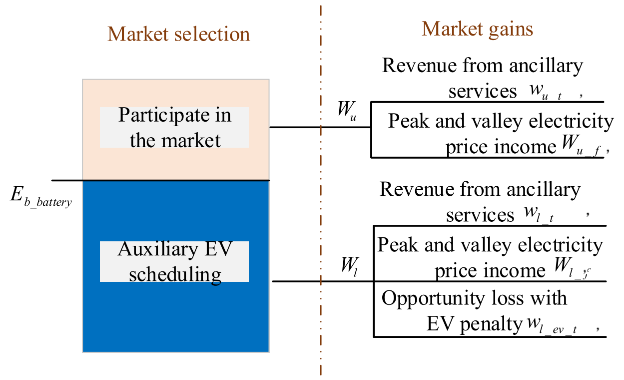

FIGURE 3. Strategies of energy storage coordination EV participating in auxiliary services.

For energy storage resources directly involved in auxiliary services: the equation for calculating the direct revenue of auxiliary services is shown in equation (16); the revenue of peak-valley tariff difference is shown in (17); and the total revenue of auxiliary services market is shown in (18).

$$w_{u,t} = K^t \times \min\left\{\frac{E_{t,b}}{P^t_{base,b}}, 1\right\} \times \min\left\{E_{t,b}, P^t_{base,b}\right\} \times t \times A^t_{out} \quad (16)$$

$$W_{u,f} = (p_p - p_v) \times Q_u \quad (17)$$

$$W_u = W_{u,f} + \sum_{t\in T} w_{u,t} \quad (18)$$

where, $E_{t,b}$ is the actual response capacity of the energy storage resource at time t; $P^t_{base,b}$ is the reported response capacity of the energy storage resource at time t; p_p and p_v are energy storage discharge price and charging price; $Q = Q_u + Q_l$ is the total energy storage capacity participating in the ancillary services market.

For the energy storage resources that coordinate EV participation in ancillary services: the revenue of their ancillary service market is shown in equation (19); the revenue of peak-valley tariff difference is shown in equation (20); the opportunity loss reduction of coordinated energy storage is calculated in equation (21); and the total revenue of coordinated energy storage is shown in equation (22).

$$\begin{aligned} w_{l,t} &= K^t \times \min\left\{\frac{\Delta E_t + E_t}{P^t_{base}}, 1\right\} \times \min\left\{(\Delta E_t + E_t), P^t_{base}\right\} \times t \times A^t_{out} - F_t \\ &= K^t \times \frac{2E_t \cdot \Delta E_t}{P^t_{base}} \times \Delta E_t \times t \times A^t_{out} \end{aligned} \quad (19)$$

$$W_{l,f} = (p_p - p_v) \times Q_l \quad (20)$$

$$w_{l,ev,t} = \gamma\left(K^t \times E_{t,b} \times t \times A^t_{out}\right) \quad (21)$$

$$W_l = W_{u,f} + \sum_{t\in T}\left(w_{u,t} + w_{l,ev,t}\right) \quad (22)$$

where, ΔE_t is the load growth caused by energy storage regulation; Q_l is the energy storage capacity for coordinating EV's participation in ancillary services; $E_{t,b}$ is the auxiliary adjustment capacity of energy storage at time t.

In the calculation of energy storage configuration cost, this paper uses the annual value calculation equation of the battery storage system proposed in literature [27] as the energy storage cost measurement method, then the annual cost of energy storage is calculated as shown in Equation (23).

$$A_b = (P_{bess} \times \alpha + E_{bess} \times \beta) \times \frac{(1+i)^{T_{life}} \times i}{(1+i)^{T_{life}} - 1} \quad (23)$$

where, A_b is the annual cost of the energy storage system; P_{bess} is the planned value of energy storage power; α is the amortization of power cost for energy storage; E_{bess} is the planned value of energy storage capacity; β is the amortization cost of storage capacity; i is the level of interest rates; T_{life} is the service life of energy storage. The calculation method of some important parameters is as follows:

$$\beta = \frac{C_E}{T_{life}} + C_m \quad (24)$$

$$\alpha = \lambda \cdot \beta \quad (25)$$

$$T_{life} = 1 \Bigg/ \sum_{i=1}^{N} \frac{1}{K_{eye,D(i)}} \quad (26)$$

$$L_{eye,D} = 694D^{-0.795} \quad (27)$$

where, C_E is the investment cost of the energy storage system; C_m is the maintenance cost of the energy storage system; λ is the ratio of power investment to capacity investment of the energy storage system; $K_{eye,D(i)}$ is the battery life when the charge and discharge depth is $D_{(i)}$; $L_{eye,D}$ is the battery life when the charging and discharging depth of the lithium battery is D.

C. MODEL FOR OPTIMAL ALLOCATION OF ENERGY STORAGE BASED ON MAXIMIZING MARKET BENEFITS

The objective function (28) is established to maximize the annual market benefits of EVA in the ancillary services market.

$$\max \ \Pr o = \sum_{d=1}^{365}\left(W^d - \sum_{t\in T} A^d_{e,t} + W^d_u + W^d_l\right) - A_b \quad (28)$$

where, d is the date count; pro is the calculation equation of the aggregator's annual profit. And optimize the energy storage capacity through optimization operation (29):

$$Q = Q_u + Q_l \quad (29)$$

Considering that the ability of energy storage to charge and discharge energy will be limited by the rated power of energy storage charging and discharging, the constraint of energy storage power is set as shown in equation (30).

$$\max_{d\in(1,365),t\in T}\left\{E^d_t\right\} \cdot (\lambda_1 - \lambda_2) \le P \cdot \Delta t \quad (30)$$

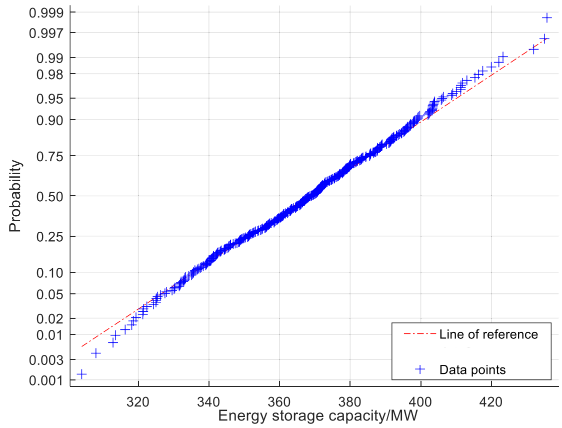

FIGURE 4. Electric vehicle load fitting results.

V. CASE STUDY

Taking the EV load situation of City A as an example, the optimal allocation capacity of energy storage for its EV participation in the auxiliary service market in North China is calculated, and the benefits and confidence levels are studied. Since the ultimate purpose of this paper is to calculate the optimal energy storage allocation capacity, the auxiliary service price and market coefficient have no direct impact on the long-term planning of energy storage, so these two coefficients are assumed to be stable.

A. SCENARIO SETTING

When configuring the scale of energy storage for coordinating EV participation in valley filling assistance, it is necessary to first determine the annual EV response scale, and then determine the deviation level of EV company participation in the auxiliary service market, based on which the scale of energy storage capacity is determined. In this case, the distribution function of short-term market participation is fitted based on the sampling of EV 2019 response capacity data in Beijing, and the one-year EV charging capacity scale is simulated by Monte Carlo; the response deviation distribution is simulated by sampling the LSSVM response capacity model.

In the fitting process, the response size of the ancillary services market was randomly sampled for 100 days to fit the distribution function. The fitting results show that the short-term response capacity size obeys a normal distribution with a mean of 368.88 and a variance of 24.34. Based on this normal distribution function, combined with the normrnd function in MATLAB, the capacity size of the EV participation market for 365 days was simulated, and the results are shown in figure 4.

The LSSVM simulation was used to calculate 960 intraday load curves, and the distribution of response deviations is shown in table 3.

Then, according to the load simulation results, the CVaR method with 90% confidence is used to measure the daily peaking reserve storage capacity, and the distribution of the measurement results is shown in Figure 5 and Figure 6. Among them, figure 5 shows the result of efficient energy storage allocation and figure 6 shows the result of promised energy storage allocation. To reflect the distribution relationship, figure 5 and figure 6 are depicted by normal distribution probability diagram.

Set the auxiliary service market error range is not more than 5%, the auxiliary service clearing price is 300 yuan/MWh; take the peak and valley power price

TABLE 3. Deviation distribution between reported capacity and actual response capacity.

Deviation interval	Count results	Probability distribution
0~0.01	245.00	0.26
0.01~0.02	260.00	0.27
0.02~0.03	168.00	0.18
0.03~0.04	109.00	0.11
0.04~0.05	68.00	0.07
0.05~0.06	50.00	0.05
0.06~0,07	27.00	0.03
>0.07	33.00	0.03

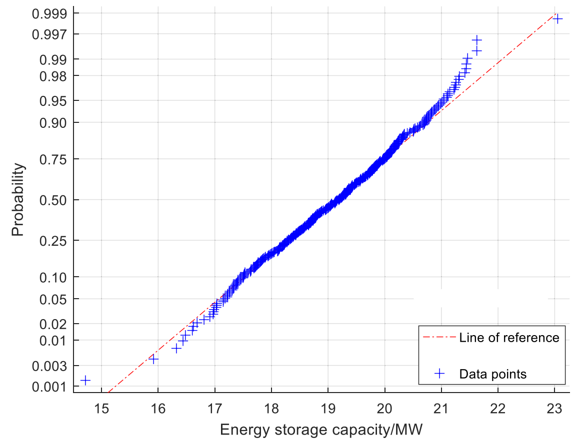

FIGURE 5. Scale of efficient energy storage.

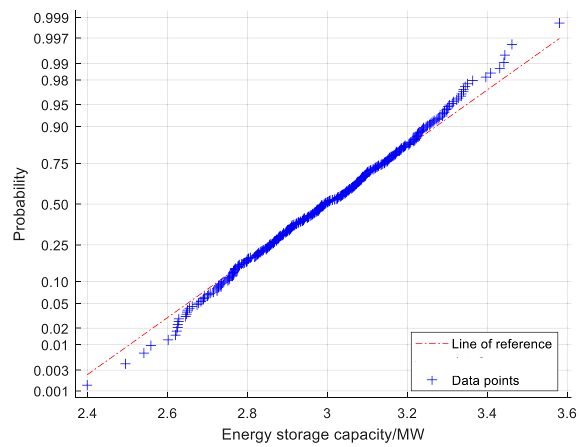

FIGURE 6. Scale of promised energy storage.

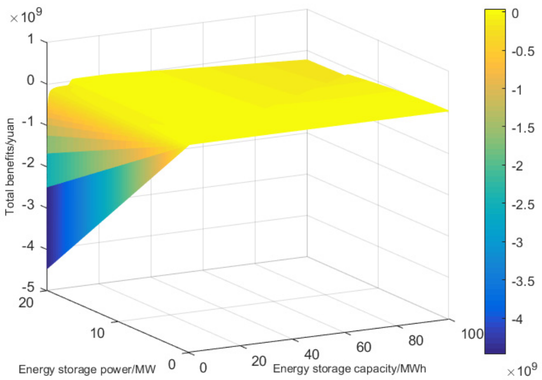

FIGURE 7. The benefits of different energy storage power and capacity configuration results.

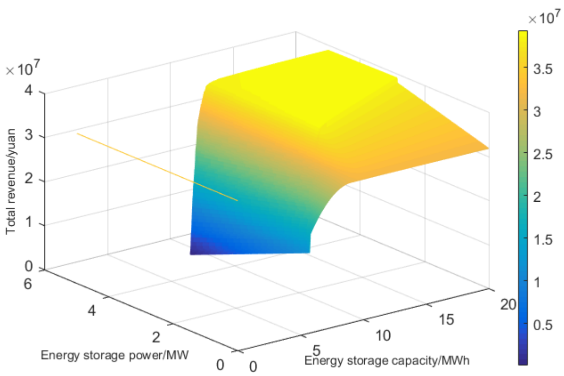

FIGURE 8. A local view of the result.

difference is 1030 yuan/MWh, the peak and flat section power price difference is 500 yuan/MWh; the investment cost is 5166000 yuan/MWh, the maintenance cost is 174000 yuan/(MWh·year) [27], the cost ratioλ is 1.172, and the market interest rate level is 8%. Accordingly, the following simulation results are obtained.

B. SIMULATION RESULTS

1) OPTIMAL ENERGY STORAGE CONFIGURATION

According to the simulation results of the above scenario, the benefits of different energy storage power and capacity configuration results when the confidence level is taken as 90% are shown in figure 7, and figure 8 shows the partial display of the results.

In the scenario set up in this paper, when no energy storage is configured, the annual benefit of EV dispatch is 33.97 million yuan; at the confidence level of 90%, the energy storage capacity configuration is 13.66 MWh and the energy storage power configuration is 1.96 MW, at which time the annual benefit of EV and energy storage joint dispatch is 39.15 million yuan, and the incremental benefit reaches 5.18 million yuan.

In this optimization problem, energy storage power investment can improve the accuracy of EVA response and also increase the total energy storage investment cost. The storage power investment within a reasonable range can improve the efficiency of EV dispatch, and the high amount of storage power construction can cause the waste of resources. Energy storage capacity is a key factor influencing energy storage to coordinate EV participation in auxiliary services, but it is easy to see from Figure 8 that when the capacity of energy storage configuration is too high it does not bring significant incremental benefits. This is due to the current high cost of energy storage allocation, and the market revenue of its participation in auxiliary services cannot compensate its cost. Only when energy storage gives full play to its coordination and dispatching function can the investment in energy storage yield positive returns.

TABLE 4. Optimal configuration scheme and benefits of storage at different confidence levels.

Confidence level	Total benefits (thousand yuan)	Energy Storage Capacity（MWh）	Energy storage power（MW）
0.05	41.70	1.03	0.12
0.1	41.63	1.88	0.18
0.15	41.55	2.22	0.23
0.2	41.45	2.64	0.31
0.25	41.38	3.02	0.4
0.3	41.70	1.03	0.12
0.35	40.90	4.00	0.58
0.4	41.05	4.7	0.68
0.45	40.54	5.19	0.75
0.5	40.71	5.89	0.85
0.55	40.54	6.45	0.93
0.6	40.67	7.22	1.04
0.65	40.29	7.85	1.13
0.7	40.40	8.62	1.24
0.75	40.37	9.46	1.36
0.8	39.66	10.37	1.49
0.85	39.77	11.77	1.69
0.9	39.15	13.66	1.96
0.95	38.47	18.56	2.66

2) ENERGY STORAGE CONSTRUCTION SCHEME AT DIFFERENT CONFIDENCE LEVELS

Under different CVaR confidence levels, the corresponding optimal energy storage construction plan is calculated, and its final results are shown in table 4.

As can be seen from table 4, as the confidence level requirements increase, the requirements for energy storage capacity and power scale also increase. This is due to the fact that the higher the reliability requirements for EV to energy storage coordination and dispatch, the more it costs and therefore more energy storage resources are needed.

3) TYPICAL DAILY MARKET SITUATION UNDER OPTIMAL ENERGY STORAGE SCALE

In the case of optimal energy storage scale, based on the relevant parameters in section 4.1, the EV and storage market operation on a typical day under this energy storage

TABLE 5. Simulation results of typical daily market operation.

The total capacity （MW）	Coordinate energy storage capacity （MW）	Ratio of EV load （%）	Ratio of energy storage load （%）	Ratio of capacity that the EV adjusted （%）	Compensated opportunity loss (yuan)
372.25	12.40	96.7%	3.3%	18.5%	4518.44
364.07	9.12	93.4%	6.6%	20.6%	4902.54
379.81	13.65	94.7%	5.3%	19.4%	4826.12
354.54	8.81	95.2%	4.8%	22.8%	5305.33
371.80	12.38	93.4%	6.6%	17.0%	4139.21
350.05	8.66	94.4%	5.6%	20.9%	4793.38

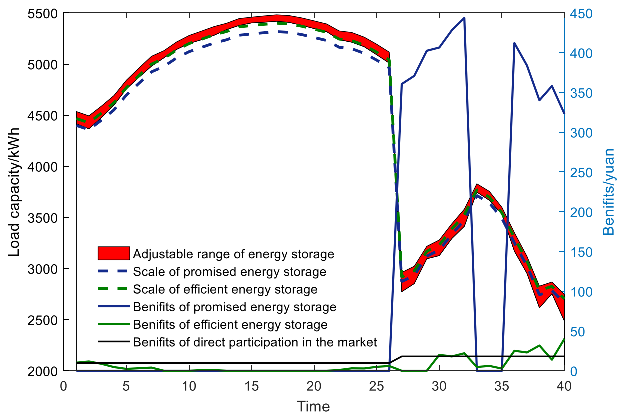

FIGURE 9. **Operation results of a typical day's EV aggregation participating ancillary service market.**

configuration is simulated. The reported capacity, EV load, energy storage load share, coordinated dispatch capacity and opportunity loss are measured, and the measured results of the auxiliary service market operation on a typical day are shown in table 5.

During the daily operation, energy storage reduces the deviation of EVs' participation in the ancillary service market through continuous adjustment of charging and discharging, thus increasing the market revenue of EVs' participation in the ancillary service as much as possible. From the overall situation of a typical daily operation, EVs are adjusted by energy storage resources to improve the response scale on the one hand, and reduce the opportunity loss caused by EV uncertainty and randomness on the other hand.

The analysis of the regulation effect of EV aggregation participation in the auxiliary service market is carried out with the energy storage resources on a certain day. According to the optimized allocation results, 12.40 MWh of energy storage capacity out of 13.66 MWh is applied to this coordinated and optimized dispatch, and 1.26 MWh of energy storage capacity is directly involved in the auxiliary service market. The final market operation results are shown in figure 9, which shows the EV load regulation and the regulation effect of energy storage during the 40 periods when the auxiliary service market is open.

It can be seen from the analysis in figure 9, that for EV aggregated participation in ancillary service market, during the period (0:30 to 7:00) when EV regulation ability is large, EV regulation ability is strong, load situation is relatively stable, and actual aggregation response basically meets the target curve, and only part of efficient energy storage is needed for coordination. However, for the period with low EV regulation capacity (12:30 to 18:00), EV load fluctuates greatly, and sufficient supporting energy storage and efficient energy storage are needed to ensure market efficiency.

In this process, the total benefit is 51259.73 yuan, among which, the incremental benefit generated through the coordinated scheduling of energy storage resources is 5008.15 yuan, including 272.80 yuan of opportunity loss made up by efficient energy storage and 4229.49 yuan of opportunity loss made up by promised energy storage. And the benefit made up by direct energy storage capacity is 505.86 yuan. Promised energy storage plays a more obvious role in the coordination and scheduling of auxiliary services.

VI. CONCLUSION

In this paper, with the objective of maximizing EV market benefits, the optimal energy storage allocation problem is studied by analyzing the characteristics and market mechanisms of energy storage coordinated EV participation in auxiliary services. At the same time, a scenario simulation of EV aggregation participation in North China auxiliary service market in Beijing proves that reasonable energy storage allocation can significantly improve EV participation in auxiliary market benefits. Accordingly, this paper mainly draws the following conclusions.

(1) Under the situation that third-party market players can participate in the auxiliary service market, EV, as an important demand-side adjustable resource, can obtain market benefits by participating in the auxiliary service market, and the energy storage allocation approach and coordinated bidding scheme considering coordinated scheduling technology can make it obtain higher market benefits.

(2) The bidding strategy for EV-storage participation in the auxiliary service market is proposed, and the CVaR method is used to calculate the storage resource capacity required for short-term EVA load adjustment, which can ensure the maximum return.

(3) It is of practical significance to consider the capacity and revenue of EV-storage participation in the auxiliary service market from the long-term and short-term perspectives; the deviation between the actual response capacity and the reported capacity in the short-term response, considering the selection of a reasonable and effective model for response capacity measurement can reduce the demand for energy storage LSSVM and other artificial intelligence algorithms are an effective method.

(4) EV is prone to market response deviation due to its randomness and volatility. The proposed bidding strategy of using energy storage resources to coordinate EV can effectively eliminate its opportunity loss, recover energy storage

investment cost and make it gain additional market revenue under the condition of considering the market interest rate level.

In addition, the magnitude of benefit loss caused by EV participation in ancillary service market transactions depends on the deviation between the reported capacity and the actual response capacity. Therefore, improving the EV regulation technology or forecasting accuracy can promote the benefits. The market performance risk cost of EVA at different confidence levels will be the direction of further research.

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