# The Design of Shared Energy Storage Trading Models

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**Abstract.** This study aims to enhance efficiency and credit risk management in the shared energy storage trading market. This paper designs three types of shared energy storage trading models including contract trading, auction trading, and spot trading. It innovatively proposes the “Price Priority, Credit Priority, Time Priority” trading rule, incorporating credit assessment into transaction matching to significantly reduce trading risks. Then, this paper introduces an improved Continuous Double Auction (ICDA) mechanism to meet the real-time trading needs of shared energy storage transaction. These findings enrich theoretical understanding and offer practical solutions, fostering sustainable energy market development and efficient resource allocation.

**Keywords:** energy market; shared energy storage; trading models; continuous double auction

## 1 Introduction

The trading modes of shared energy storage can be broadly summarized into bilateral trading and auction mechanisms. Bilateral trading, characterized by spontaneity, flexibility, incentives, and combinability, leverages information exchange to actively engage more market participants [1-3]. Auction mechanisms scientifically reflect the complementary and substitutable storage demands of users, addressing complexities in bilateral trading such as multilateral conflicts, complex settlement rules, and prolonged independent cycles [4-5].

Overall, the transaction models of power market include the medium- and long-term transactions and spot transaction [6], as illustrated in Figure 1. The modes of medium- and long-term transactions in power markets can be categorized into two primary types: bilateral negotiations and centralized trading. Centralized trading, in turn, comprises three forms: centralized auction, rolling match transactions, and listing transactions. Market participants in power systems have the flexibility to opt for the transaction mechanism that best suits their needs.

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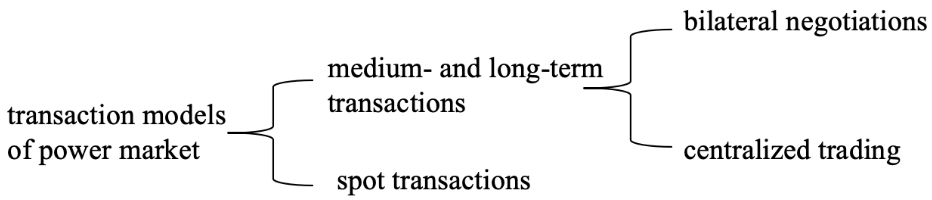


**Figure 1.** The contract trading model

Based on the current medium- and long-term transaction rules and spot trading model in power markets, this paper designs three types of shared energy storage trading models including contract trading, auction trading, and spot trading. The innovation of this article is reflected in three aspects: Firstly, the article constructs various shared energy storage business models, including long-term contract trading, auction trading, and short-term spot trading, providing new ideas for achieving shared energy storage resources, maximizing benefits, and ensuring stable market operation. Secondly, the article introduces the improved Continuous Double Auction (ICDA) mechanism into the spot trading market, encouraging both buyers and sellers to participate in action simultaneously. This design creates a more dynamic and efficient distributed electricity spot trading model, optimizing market response speed and resource allocation efficiency. Thirdly, considering the importance of credit risk in shared energy storage trading, the article innovatively proposes the "price priority, credit priority, time priority" trading rules. By using the credit rating of participants as one of the important criteria for transaction matching, it promotes the reduction of transaction risks and enhances the efficiency of the shared energy storage market.

## 2 Design of a shared energy storage trading model & credit evaluation system

The design of a shared energy storage trading model involves several transaction entities: residential users, industrial and commercial users, grid enterprises, and electricity aggregators.

(1) Residential Users and Industrial/Commercial Users. Residential and industrial/commercial users act as both investors and consumers in this business model. They can invest in the construction and operation of energy storage equipment by energy storage merchants, earning dividends from the profits of market transactions. Alternatively, they can participate in market transactions for shared energy, purchasing electricity from energy storage merchants or leasing energy storage equipment to meet their electricity and energy storage needs. When users generate surplus electricity, they can sell the excess power to energy storage merchants for profit. Conversely, when additional electricity is needed, they can purchase it from energy storage merchants.

(2) Energy storage merchants are responsible for managing users' energy storage equipment to ensure its normal operation. The revenue of electricity aggregators comes from two sources. Firstly, through contract trading, energy storage merchants establish energy trading contracts and charge users a certain capacity price to cover the costs of providing trading platforms and managing users' energy storage equipment. Secondly, energy storage merchants can generate

revenue through market-based trading, conducting energy trading through trading platforms. They purchase energy during off-peak hours and sell it during peak hours to achieve peak shaving and valley filling.

(3) Grid enterprises are third-party participants in this business model. They primarily provide transmission and distribution services involved in energy storage trading processes and charge certain network fees. Additionally, grid enterprises can purchase energy storage services from energy storage merchants to balance grid loads and ensure the supply and quality of electricity.

The trading credit evaluation system encompasses several key facets: “Contract Fulfillment” (encompassing contract breach frequency and transaction evaluation ratings), “Industry Supervision” (including records of administrative penalties and market regulation distrust actions), “Trading Performance” (covering traded volume and prices, settlement periods, and dispatch management), and “Judicial Rulings” (such as designations as untrustworthy enforcement subjects and records of administrative adjudications). This comprehensive credit assessment framework integrates both positive and negative indicators. It obligates market participants to periodically submit pertinent data to the designated authorities, enabling a thorough assessment of their credibility and operational status. The credit scores of trading entities are updated at the conclusion of each trading cycle, reflecting their ongoing performance and trustworthiness in the market.

The calculation approach of the credit scores of trading entities using the machine learning methods, referring to Wei & Luo (2007)[7]: first applying unsupervised machine learning techniques for credit clustering of trading entities, followed by employing the Entropy Weight Method (EWM) to calculate the weights of various indicators in electricity trading. These weights are then utilized to construct a weighted aggregation, forming the K-means-EWM Electricity Trading Credit Evaluation Model. This hybrid model combines the clustering ability of K-means to categorize trading entities based on their credit characteristics with the EWM’s capability to prioritize influential indicators, thereby enhancing the accuracy and robustness of credit assessments in the electricity trading domain.

(1) Normalize the initial indicator values to address differences in scale and units, eliminating their impact on electric customer credit assessments – this step is known as data normalization. Given n trading entities under evaluation and m chosen evaluation criteria, denote the value of the j-th criterion for the i-th entity as $x_{ij}(i = 1, \dots n; j = 1, \dots m)$。 The standardized data for the i-th customer's j-th attribute is represented as formula (1).

$$\boldsymbol{x^{*}}_{ij} = {(\boldsymbol{x_{ij}} - \boldsymbol{mean_j})} \Big/ \boldsymbol{\sigma_j}, \qquad (\boldsymbol{i} = \boldsymbol{1}, \dots \boldsymbol{n}) \tag{1}$$

(2)Using K-means with a predetermined number of customer categories k, n electricity customers are divided into K clusters based on the principle of minimizing distances between samples. The K cluster centers represent the outcomes of clustering. The objective function for the clustering process is as formula (2).

$$\mathrm{J} = \sum_{k=1}^{K} \sum_{X_j \in G_i} d_{ik}(X_i, C_k), \qquad k = 1, \dots, K; i = 1, \dots, n \tag{2}$$

$d_{ik}(X_i, C_k)$ denotes the distance between the features of sample $X_i$ and the cluster center $C_k$, with the distance function optionally being the Euclidean distance, Manhattan distance, or cosine similarity. After several iterations aimed at optimizing the clustering distances, the ultimate result yields K distinct clusters and K cluster centers, as formula (3).

$$\boldsymbol{G_k}^*, \boldsymbol{k} = \boldsymbol{1}, \boldsymbol{2}, \dots, \boldsymbol{K}; \ \boldsymbol{C_k}^* = (\boldsymbol{c_{k1}}, \dots, \boldsymbol{c_{kp}}), \boldsymbol{k} = \boldsymbol{1}, \boldsymbol{2}, \dots, \boldsymbol{K} \tag{3}$$

(3)Using the weights $W = (w_1, \dots, w_p)$, calculated by the entropy weight method, and after obtaining the centroid of each cluster $C_k^* = (c_{k1}, \dots, c_{kp}), k = 1,2, \dots, K$, the comprehensive credit evaluation score for the K classes of electricity market participants can be computed using the following formula (4):

$$\boldsymbol{A_k} = \boldsymbol{W}\boldsymbol{C_k}^* = (\boldsymbol{w_1}, \dots, \boldsymbol{w_p})(\boldsymbol{c_{k1}}, \dots, \boldsymbol{c_{kp}})^{\boldsymbol{T}}, \boldsymbol{k} = \boldsymbol{1}, \boldsymbol{2}, \dots, \boldsymbol{K} \tag{4}$$

## 3 Design of contract trading model

In the contract trading model, users engage with energy storage merchants through agreements for charging and discharging, or leasing energy storage equipment. As per contract terms, energy storage merchants discharge energy during peak hours and charge during off-peak hours. The steps involved in contract trading on the platform include declaration and retrieval, matching, transaction matching, clearance, and transaction settlement, as Figure 2.

**Step 1:** Declaration and Retrieval. Firstly, energy storage suppliers declare energy supply information on the platform, including energy storage capacity, trading period, trading location, and willingness price. Secondly, energy storage users input purchase demand information for retrieval on the trading platform.

**Step 2:** Matching. After submitting search criteria, the power trading platform will match energy storage suppliers that meet the conditions for energy storage users based on smart contract systems, and present them to users in the form of lists or tables.

**Step 3:** Transaction Matching. Users choose transaction partners matched by the system for communication and negotiation. After bilateral consensus, transactions are matched on the power trading platform.

**Step 4:** Clearance. The platform provides transaction confirmation functionality. After both parties confirm the transaction details are correct, the platform forms clearing transaction pairs and sends transaction information to the dispatch center for safety verification.

**Step 5:** Settlement. After the transaction results are verified for safety, the power trading department conducts final transaction settlement, including contract fees, variance assessment, and network charges (calculated according to existing regulations).

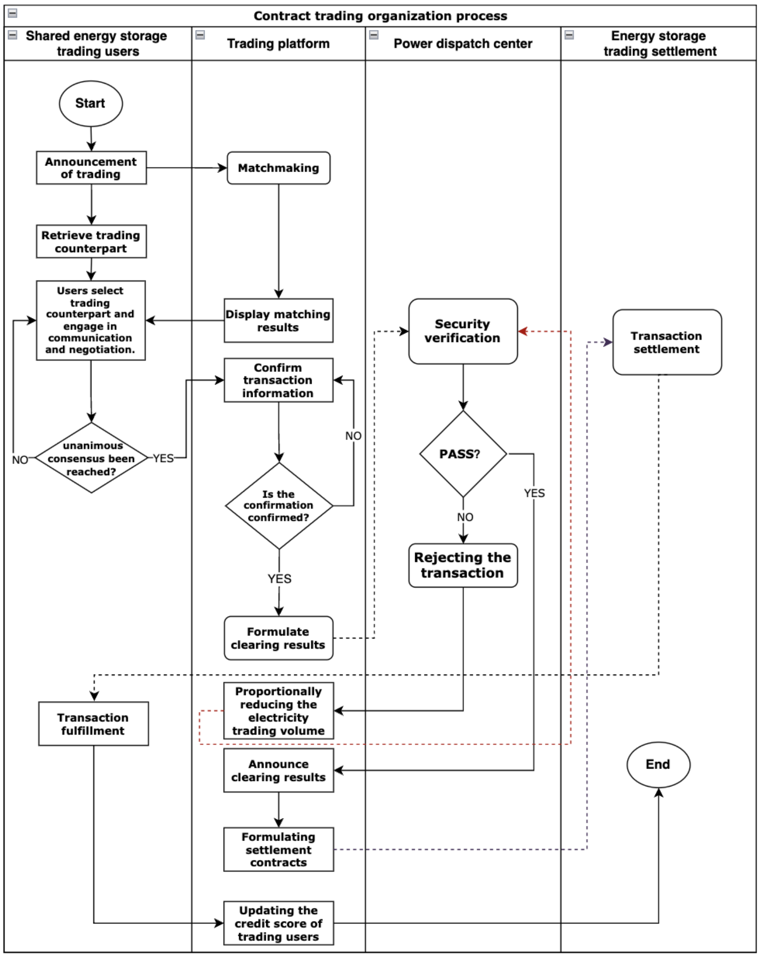


**Figure 2.** The contract trading model

## 4 The action trading model

Energy storage operators and demand-side participants declare the supply/demand and pricing of energy storage facility charging/discharging quantities to the system through the platform. The platform facilitates bilateral negotiations to conduct competitive action between supply and demand sides. Drawing from the "*Notice on Improving the Pricing Mechanism of Pumped Storage Power Stations*" issued by the National Development and Reform Commission of China and the "*Opinions on Implementing the Pricing Policy of Pumped Storage*" issued by State Grid Corporation of China, shared energy storage transactions adopt a dual pricing system, comprising capacity and energy prices. The capacity price is determined based on the fixed costs and permitted revenue of the energy storage equipment, with the purchasing party paying capacity fees according to the agreed time limit. The energy price is determined based on the contract price formed through transactions. Centralized action trading enhances the flexibility and market competitiveness of energy storage resources, making energy trading more efficient and transparent. The steps involved in centralized action between energy storage merchants and demand-side participants on the trading platform include transaction declaration, demand invitation, action clearance, transaction execution, and settlement, as shown in Figure 3.

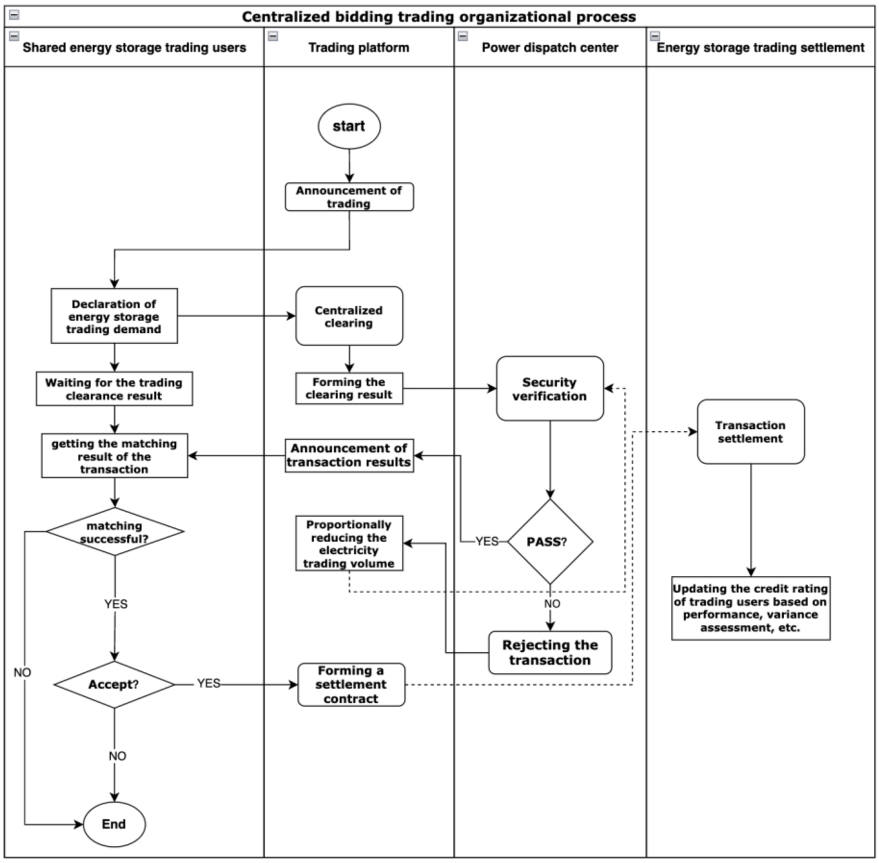


**Figure 3.** The action trading model

**Step 1: Transaction Announcement.** The trading platform regularly publishes announcements for electricity transactions on various periods such as yearly (multi-year), monthly (multi-month), etc. Trading parties must complete transaction demand declaration within the declared time period.

**Step 2: Transaction Demand Declaration.** Power generators, electricity users (electricity aggregator companies) declare transaction quantities, electricity prices, and other information to the trading platform within the specified time limit. Transactions can be conducted in multiple rounds, but not exceeding 3 rounds. The declared quantity by both parties should not be less than 1000 megawatt-hours, and the declared electricity price should be accurate to 0.1 yuan per megawatt-hour.

**Step 3: Platform Clearance:** (1) After the deadline for transaction demand declaration, the power trading platform collects the demands of both trading parties. Electricity users (aggregator companies) are sorted in descending order of declared electricity price (deducting transmission and distribution costs, government funds, and surcharges, converted to the level of power generation). Power generators are sorted in ascending order of their declared electricity price. In case of the same bid price, transaction users are ranked according to their credit ratings.

(2) Clearing rules: For market participants such as energy storage suppliers/users, they are arranged in descending order of credit rating, ascending order of declared prices, and chronological order of declaration time; Matching is carried out sequentially based on the ranking of both buying and selling parties. When the prices are the same and the credit ratings and declaration times are consistent, and the declared quantities cannot all be traded, the traded quantities are allocated according to the principle of proportional distribution based on the declared quantities.

**Step 4: Settlement.** After the transaction results are verified for safety, the power trading department conducts final transaction settlement, including contract fees, variance assessment, and network charges (calculated according to existing regulations).

## 5 Spot Trading model

Considering that contract trading model and action trading model are mainly suitable for medium and long-term markets [8] with fewer trading entities and larger transaction volumes, while shared energy storage may present characteristics of multiple participants, small transaction volumes, and short transaction cycles. Therefore, this paper innovatively proposes a new mechanism for shared energy storage spot trading.

**(1) Trading Form and Trading Time Definition**

Trading form: shared energy storage transactions are conducted in the form of “bid and ask, continuous double-sided auction clearing”. Trading time definition: each trading period lasts for 15 minutes, and there are 96 trading periods in each operating day.

**(2) Trading Declaration**

The action rules are as follows:

- Both buyers and sellers can participate in and adjust their bids at any time during each trading cycle.
- Before trading begins, the trading platform will determine whether trading blockages may occur based on the input and output power of each branch. For lines with blockages, the impact of each transaction pair on the blockage is calculated, and corresponding blockage prices are set for trading users. Users can choose whether to update their bid information based on the blockage price information.
- When submitting bid information, both buyers and sellers synchronize the credit rating range of the intended accepting trading partner based on their risk preferences. Credit status is assessed based on the user’s historical transaction information. The platform conducts credit

evaluations based on each user's transaction information, and records and updates them in real time.

**(3) Trading Rules**

Transaction matching rules:

- Two prerequisites must be met for the matching of trading parties: first, the bid price must not be less than the ask price; second, the credit ratings acceptable to both buyers and sellers.
- Trading matching is based on the principle of credit priority, price priority, and time priority. The priority order is: credit priority > price priority > time priority.
- The principle of credit priority at the time of transaction is that applicants with higher credit have priority over those with lower credit.
- The principle of price priority at the time of transaction is: for the same direction of trade and the same credit rating, a higher bid price takes priority over a lower bid price for buying, and a lower ask price takes priority over a higher ask price for selling.
- The principle of time priority at the time of transaction is: for the same direction of trade, the same credit, and the same price, the earlier applicant takes priority over the later applicant. The order is determined by the time when the transaction host accepts the bid.
- During the auction process, the trading platform also needs to conduct a safety check on the auction results to determine whether the conditions of the power flow constraint are met. For transactions that do not meet the power flow constraint, users need to adjust the transaction volume and re-execute the auction until the requirements are met.

**(4) Determination Rules for Transaction Prices:**

- If the bid price and ask price are the same, that price is the transaction price.
- If the bid price and ask price are different, the transaction price is the one that benefits the bidder with the higher credit.
- If the bid price and ask price are different and the credit is the same, the transaction price is the bid price of the bidder who bid first.

**(5) Pricing Clearance Mechanisms**

The pricing clearance mechanism employs an Improved Continued Dual Auction (ICDA) method, which differs from conventional CDAs by introducing credit evaluations of power trading entities and their trading timestamps into the CDA [9-10], proposing the ICDA (Improved Continuous Double Auction mechanism, see Figure 4). Trading Rules of ICDA:

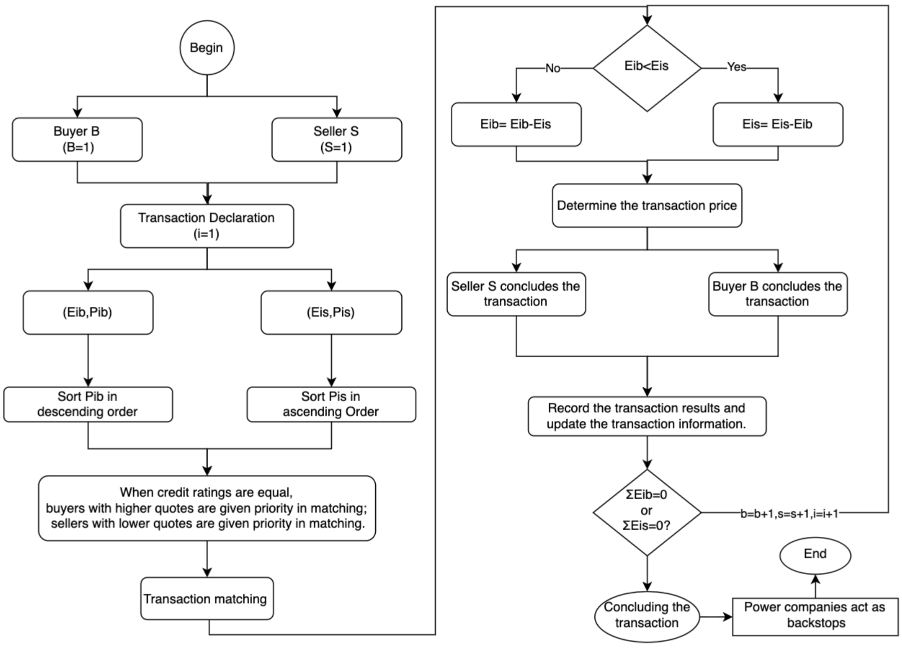


**Figure 4.** ICDA process

## 6 Conclusion

This paper designs and analyzes three distinct transaction models for the shared energy storage market: contract trading, bidding trading, and spot trading. Of particular note, the spot trading model innovatively integrates an Improved Continuous Double Auction (ICDA) mechanism borrowed from the securities market, enabling simultaneous bidding by both buyers and sellers, significantly enhancing transaction efficiency and market responsiveness. Moreover, the paper introduces a pioneering "Price Priority, Credit Priority, Time Priority" rule for transaction matching, incorporating participants' credit ratings into the matching criteria. This not only optimizes conventional auction mechanisms but also regulates market participants' behaviors effectively, reducing credit risks. Collectively, these three models and their accompanying mechanisms provide a more flexible, efficient, and secure framework for the operation of the shared energy storage market, contributing importantly to the optimal allocation of energy resources and the healthy development of the market.

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