Inter-provincial Spot Market Mechanism and Inter-provincial Trading Decision System Research

Shijian Liu

55365495@qq.com

Wuling Power Corporation Limited, Wuling Road, Tianxin District, Changsha City, Hunan Province, China

Abstract—This paper aims to investigate the development and operation of electricity spot markets and explore inter-provincial trading models under the provincial spot market rules and the unified national electricity market. Firstly, an introduction and analysis of mature electricity spot markets abroad and domestic electricity spot pilot projects are provided. Additionally, the positioning of inter-provincial electricity spot markets and the principles of transaction clearing are discussed. The paper analyzes the inter-provincial power trading mechanisms in the State Grid and Southern Power Grid regions, and provides a forward-looking study on inter-provincial trading in the context of a unified national electricity market. Through a comprehensive study of relevant literature and practical cases both domestically and internationally, it is found that the electricity spot market, as a crucial part of the power market reform, plays an important role in the rational allocation of power resources and market-based transactions. However, there is also a need for further research into the inter-provincial spot market mechanisms and trading decision systems, deepening the understanding and mastery of market rules and regulatory mechanisms, and promoting the development of the electricity spot market towards a more stable, transparent, and equitable direction, providing strong support for the smooth progress of China's power market reform.

Keywords-component; Electricity Spot Market; Trading Models; Decision System; Spot Decision

1 Introduction

With the continuous development of the Chinese economy and the accelerated process of marketization, economic exchanges and trade activities among provinces have become increasingly frequent. The inter-provincial spot market, as a significant platform for inter-regional trade, plays an increasingly important role in promoting regional economic development and strengthening economic ties between regions. However, the inter-provincial spot market still faces a series of issues and challenges, such as information asymmetry, insufficient trading rules, and high transaction costs, which hinder its healthy development. Therefore, in order to promote the development of inter-provincial spot markets in China and enhance the decision-making system for inter-provincial transactions, it is necessary to conduct in-depth research on the mechanisms of inter-provincial spot markets and the trading decision system. This paper aims to explore these issues, providing insights to facilitate the healthy and stable development of inter-provincial spot markets in China.

ICEMBDA 2023, October 27-29, Tianjin, People's Republic of China

DOI 10.4108/eai.27-10-2023.2341968

2 Analysis of Typical Electricity Spot Markets at Home and Abroad

2.1 Construction and Operation of Mature Electricity Spot Markets Abroad

There are numerous mature electricity markets established abroad, which play significant roles in various aspects such as promoting market competition, improving electricity resource allocation efficiency, and reducing power costs[1]. The following provides an overview of the construction and operation of some typical mature electricity spot markets overseas:

2.1.1 PJM Electricity Spot Market in the United States

The PJM (Pennsylvania-New Jersey-Maryland) electricity market is one of the largest electricity spot markets in the United States. PJM's spot market is divided into two levels: the day-ahead market and the real-time market. Trading targets in PJM include both electricity and ancillary services (reserve and frequency regulation). The market operates on a full-quantity optimization model, where generators need to declare all their generation resources and trading intentions in the day-ahead market. The market matches the entire network's load demand, calculates the day-ahead transaction plan for generators through rigorous clearing, and settles the transactions at full value based on node marginal prices.

The PJM electricity market in the United States adopts a nodal marginal pricing mechanism and a pricing mechanism based on network-wide marginal clearing prices, ensuring fairness and transparency in market transactions, while also avoiding speculative trading behavior among market participants. Furthermore, PJM's market power suppression mechanisms include the three-head test, cost-based bidding mechanism, and resource scarcity price limits, ensuring the reliability and stability of system operation.

The operational mechanism of the PJM electricity market has become a valuable reference for the development of electricity markets in other countries and regions. Through optimized allocation and cost reduction in market transactions, market participants can achieve better economic and societal benefits, while also providing effective market mechanisms and operational experience for the sustainable development of the electricity market.

2.1.2 Electricity Spot Market in the United Kingdom

The electricity spot market in the United Kingdom is one of the earliest established electricity markets in Europe. Its full name is the National Grid Electricity Market, also known as the N2EX market. The UK electricity market primarily operates through four trading mechanisms, including over-the-counter bilateral trading, on-exchange standard contract trading, day-ahead electronic trading, and real-time balancing mechanisms. Additionally, the UK has achieved certain accomplishments in electricity financial trading, which mainly occur on the Amsterdam Power Exchange and NASDAQ Exchange. Day-ahead electronic trading is organized separately by APX and the Nord Pool and NASDAQ jointly-operated spot electricity exchanges. Market members voluntarily select and participate in these exchanges, creating a competitive landscape among electricity trading platforms.

2.1.3Nordic Electricity Spot Market

The Nordic electricity market, also known as Nord Pool, is one of the world's earliest established multinational electricity spot markets. The Nordic electricity market primarily consists of medium to long-term bilateral trading, day-ahead market, intraday market, and real-time balancing market. In 2008, the responsibility for electricity financial trading within the Nord Pool was transferred to NASDAQ Exchange for organization. The trading focus of the Nordic electricity market is on electricity energy. The trading mechanism for ancillary services is similar to that of the United Kingdom.

From a structural perspective, the aforementioned three countries or regions have each established distinct electricity spot market systems, and these market systems are closely related to the top-level design and conceptualization of the entire market. The successful operation of these markets is largely attributed to the adaptability of their design concepts and construction plans, as well as the abundant resources and robust grid infrastructure unique to each country.

2.2 Introduction to Domestic Electricity Spot Pilot Projects

In 2017, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) issued the "Notice on Pilot Work of Electricity Spot Market Construction" (NDRC Energy [2017] No. 1453), which established the first batch of electricity spot pilot regions in China[2]. These regions include Guangdong, Gansu, Inner Mongolia West, Shanxi, Fujian, Sichuan, Zhejiang, Shandong, and others. The trial operation of electricity spot market settlements has been conducted several times since 2019 in these regions with varying settlement periods. During the pilot process, a variety of trading methods such as "bilateral negotiation, auction trading, and direct trading" have been adopted, gradually establishing the basic rules and trading procedures of the electricity spot market.

In the initial stage of the pilot, due to issues such as incomplete market mechanisms, less stringent market supervision, and limited diversity in trading participants, the electricity spot market exhibited certain instability and risks. As relevant rules and regulatory mechanisms continue to improve, the electricity spot market has gradually developed into an essential component of China's electricity market, further propelling the progress of the electricity market liberalization.

Building upon the foundation of the first batch of pilot provinces, a second batch of electricity spot pilot provinces was introduced, including Liaoning, Shanghai, Hubei, Anhui, Henan, and Jiangsu. This expansion aimed to further accelerate the development of China's electricity spot market. As for the progress of the second batch of pilot projects, each pilot has completed the formulation of electricity spot operational rules. They have subsequently initiated simulated, dispatch-related, or settlement trial runs in accordance with the progress of market development.

From the current state of China's electricity market development, the medium to long-term market has reached a relatively mature stage. The first batch of spot market pilots has successively conducted settlement trial runs, and the second batch of spot market pilots has begun to establish electricity spot trading rules. A market system featuring a combination of

medium to long-term contracts and spot trading is taking shape. For a comprehensive summary of domestic electricity spot pilot projects, please refer to Appendix 1.

3 Study on Inter-Provincial Spot Market Rules and Inter-Provincial Trading Models in the Unified National Electricity Market

The formulation of inter-provincial spot market rules requires consideration of various factors such as market transparency, fair competition, and transaction security to ensure the stable operation of the market. Additionally, exploring the establishment of suitable inter-provincial trading models within the framework of a unified national electricity market is also a topic that merits in-depth investigation. Different provinces possess distinct electricity demands and resources. Determining how to rationally allocate electricity resources, achieve resource sharing, and optimize allocation is a critical task in constructing effective inter-provincial trading models. In recent years, relevant research institutions and scholars have conducted extensive studies and discussions on inter-provincial spot market rules and inter-provincial trading models within the context of a unified national electricity market[3].

3.1Positioning of Inter-Provincial Electricity Spot Market and Transaction Clearing Principles

On November 22, 2021, State Grid Corporation of China (SGCC), in accordance with the requirements of the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) as outlined in the "Reply on Inter-Provincial Electricity Spot Trading Rules of State Grid Corporation of China" (NDRC Reform [2021] No. 837), officially issued the "Inter-Provincial Electricity Spot Trading Rules (Trial Implementation)." The issuance of these rules signifies a significant step forward for China in constructing a "unified market with dual-level operation" electricity market system, marking an important milestone in the development of China's electricity spot market[4].

China's electricity market system is continuously evolving. According to investigations, the medium to long-term electricity trading mechanisms between provinces and within provinces have all been established and are operating routinely. However, a complete inter-provincial electricity trading system at the provincial level has not yet been formed. Only cross-regional inter-provincial electricity trading has been conducted, mainly involving surplus renewable energy resources. Therefore, vigorous efforts will be needed in the future to develop inter-provincial electricity spot markets, in order to implement the national energy strategy, promote the large-scale optimized allocation of clean energy resources, and tap into the hidden potential within.

3.1.1 Key Contents of Inter-Provincial Electricity Spot Trading Rules

The "Inter-Provincial Electricity Spot Trading Rules (Trial Implementation)" primarily consist of the following key contents, divided into thirteen chapters: including overarching principles, transaction organization, participant management, different trading phases, execution and resolution of deviations, measurement methods, risk management, information disclosure, contract administration, and more, this is shown in Fig 1.

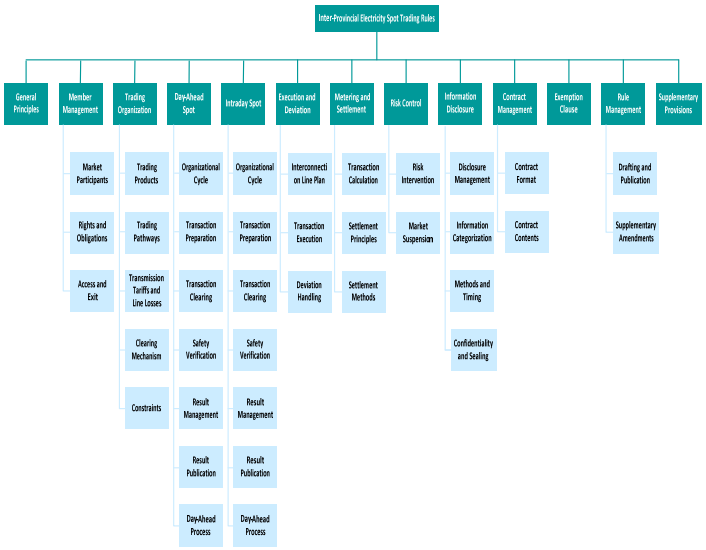

Fig 1. Framework of State Grid Inter-Provincial Electricity Spot Trading Rules

The positioning of inter-provincial electricity spot trading is aimed at constructing a comprehensive unified market system both between provinces and within provinces, this is shown in Fig 2. This positioning is designed to accommodate the dynamic variations in renewable energy generation and grid load demands. Such a trading mechanism enables the optimal allocation and sharing of electricity resources among regions, addresses the volatility of renewable energy, and promotes the development and utilization of clean energy. Moreover, it forms an integral part of the national energy strategy by achieving interconnection between intra-provincial and inter-provincial electricity markets, thereby propelling the integrated development of the electricity market[5].

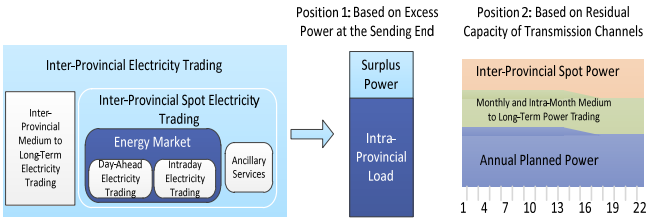

Fig 2. Positioning of Inter-Provincial Spot Electricity Trading

Participants in the inter-provincial electricity spot market include power generation companies, grid enterprises, electricity retailers, power consumers, and market operators, among others, the market composition is shown in Fig 3. Grid enterprises represent intra-provincial users in inter-provincial spot trading and encourage participation from green energy consumers and new energy generation companies. This participation is aimed at accelerating the development of relevant policies and mechanisms [5].

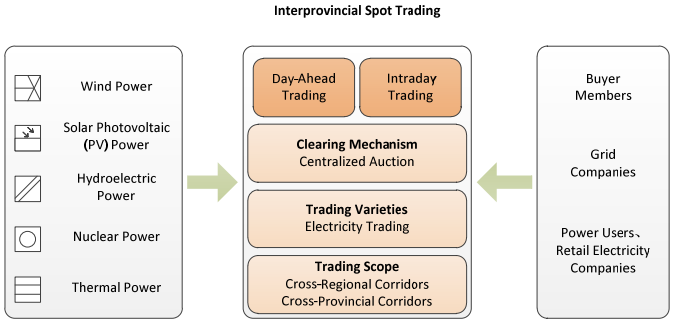

Fig 3. Market Participants of Inter-Provincial Spot Electricity Trading

Inter-provincial electricity spot trading involves a wide distribution and diverse range of market participants, posing challenges in grid security control. It requires the coordination and organization of various levels of grid dispatching agencies and trading center systems to carry out market operations. The purpose of spot trading is to adapt to the dynamic changes in renewable energy generation and grid load demands within the electricity market, serving as one of the ways to achieve market-based transactions[6].

Inter-provincial electricity spot trading primarily consists of two forms: inter-provincial day-ahead spot trading and inter-provincial intraday spot trading. Among them, inter-provincial day-ahead spot trading occurs once per day. Between 11:00 AM and 11:30 AM on a trading day, market participants can declare their hourly "electricity-price" purchase and sale curves. The centralized clearing for inter-provincial day-ahead electricity spot trading is completed by 12:30 PM on the same day [8].

The process of day-ahead spot trading can be roughly divided into five main stages:

- National and regional dispatch issuing inter-provincial preliminary plans.
- Intra-provincial market pre-clearing (or forming preliminary plans).
- Inter-provincial spot market trading declaration.
- Inter-provincial spot market clearing.
- Completion of inter-provincial interconnection line planning.
- Completion of intra-provincial generation planning (market clearing).

The organizational process of the inter-provincial spot market is shown in Fig 4 below.

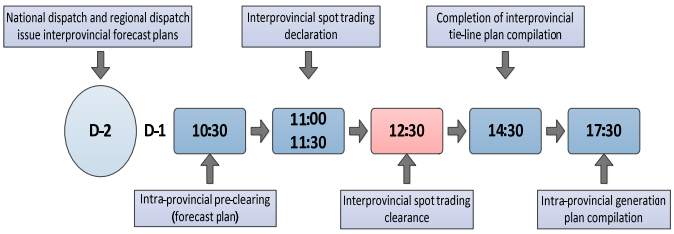

Fig 4. Organizational Process of Inter-Provincial Day-Ahead Spot Electricity Trading

The intraday inter-provincial spot market operates with a fixed trading cycle of 2 hours. The organizational process of the intraday inter-provincial spot market is illustrated in Fig 5.

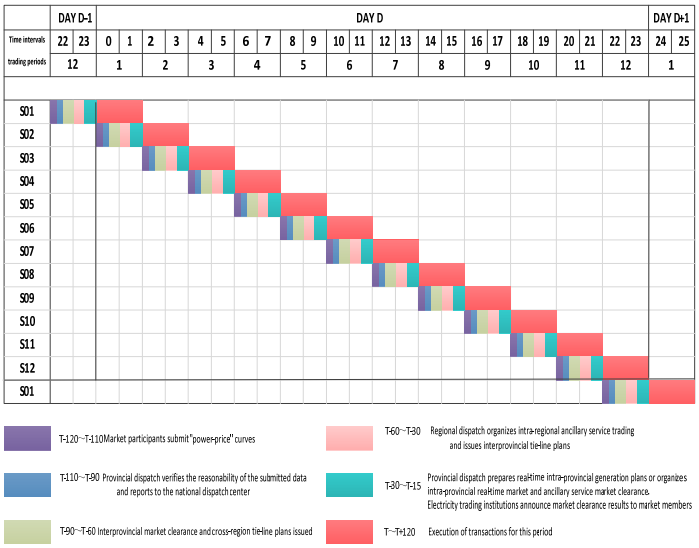

Fig 5. Organizational Process of Inter-Provincial Intra-Day Spot Electricity Trading

The inter-provincial spot market adopts a centralized auction clearing method, consisting of five steps: electricity price conversion, transaction pair matching, traded volume allocation, congestion management, and calculation of clearing electricity price[9]. The clearing process is illustrated in Fig 6.

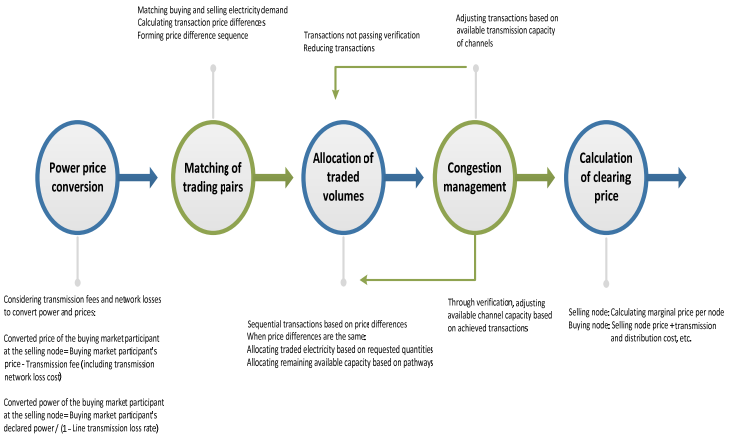

Fig 6. Inter-Provincial Spot Electricity Trading Clearing Process

Both the buying and selling parties declare their local "electricity-price" curves for purchasing and selling electricity. The technical support system converts the electricity and price declared by the buying side, considering transmission fees and network losses. It calculates and

matches them along the trading paths to the selling-side nodes for centralized sorting and pairing. The selling party with the lowest bid and the buying party with the highest bid are prioritized for the transaction. The average of the last transaction prices at the selling-side node serves as the marginal clearing price for selling electricity[8]. The pricing method is illustrated in Fig 7. In the inter-provincial spot market, if the last transaction price from a buying party is 400 CNY/MWh, and the last transaction price from a selling party is 300 CNY/MWh, then the final transaction price would be 350 CNY/MWh.

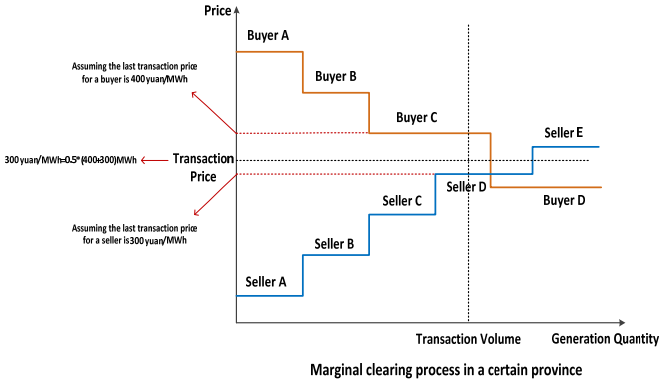

Fig 7. Pricing Mechanism for Inter-Provincial Spot Electricity Trading

Compared to cross-regional inter-provincial surplus renewable energy spot trading, the inter-provincial spot trading rules possess the following characteristics:

- Broader Market Coverage: The market coverage is wider and more extensive.
- Advance Timing and Increased Frequency: Trading timing is earlier, and trading frequency is higher, with a more refined trading mechanism.
- Flexibility in Participant Roles: Market participants have greater flexibility in transitioning between roles during inter-provincial electricity spot trading.
- Enhanced and Efficient Clearing Mechanism: The market clearing mechanism is more advanced and efficient.
- Standardized and Transparent Information Disclosure: Information disclosure is more standardized and transparent.
- Encouragement of Market-Based Deviation Adjustment: The rules promote the use of market-based methods for deviation adjustment.

3.1.2 Southern Region Unified Spot Market

In contrast to the positioning of the inter-provincial spot market in the State Grid region, the construction of the Southern Region Unified Spot Market is oriented towards the unified optimization of all provinces and regions within the southern area, encompassing power resources beyond mere incremental optimization. However, in practice, currently, only Guangdong province conducts spot trading within the southern region. Other provinces are still in the exploratory phase of spot market development. Due to disparities in the

development progress of electricity markets among provinces within the southern region, the initial stage of the Southern Region Unified Spot Market focuses solely on optimizing interconnection line plans within the region. The clearing results are utilized as boundary conditions for spot market clearing within Guangdong province[10].

3.2Comparative Analysis of Inter-Provincial Electricity Trading Mechanisms in State Grid and Southern Region

When comparing the inter-provincial spot markets in the State Grid region and the Southern region, the main differences lie in the following aspects:

- Positioning: The primary distinction is in their positioning. In the State Grid region, inter-provincial spot trading serves as a complement to intra-provincial spot trading. In contrast, the Southern Region Unified Spot Market is aimed at unified optimization of all market resources within the southern area.
- Clearing Model: The clearing models also differ. In the State Grid region, inter-provincial spot trading optimizes for maximum welfare in inter-provincial power purchases during clearing. On the other hand, the Southern Region Unified Spot Market optimizes for minimal regional market power purchase costs during clearing.
- Pricing Mechanism: The pricing mechanisms are distinct. In the State Grid region, the inter-provincial spot trading settles on the average of marginal transaction bid prices. Meanwhile, the Southern Region Unified Spot Market employs a nodal pricing mechanism.

3.3Prospects of Inter-Provincial Trading Under the Context of National Unified Electricity Market

In accordance with China's national conditions and power technology, the development of domestic intra-provincial and inter-provincial electricity markets is anticipated to unfold in three phases within the framework of a national unified electricity market: tiered clearing, basic coupling, and comprehensive coupling. The forms of these three stages will be outlined as follows:

3.3.1Tiered Clearing Stage

Taking the cross-regional long-term trading rules within the State Grid region as an example, market participants include power generation companies, electricity retailers, power users, and grid enterprises. Power generation companies encompass not only conventional thermal power but also new energy sources such as wind and photovoltaic power. In addition to acting as agents for priority power purchasing users, grid enterprises can also participate in inter-provincial markets, including inter-provincial priority plans and purchasing sides. Prior to complete liberalization, power users not engaged in market-based transactions can procure electricity through grid enterprises. Electricity retailers and users need to possess technical support capabilities that meet the requirements for participating in inter-provincial transactions and adhere to electricity market entry rules. Currently, the most widely adopted bidding method in China's electricity market is centralized auction trading, employing ordinary hourly bidding to declare information such as segmented electricity volumes and prices, with power generation units serving as bidding units.

Regarding market clearing, the current inter-provincial and intra-provincial markets employ a "tiered declaration, sequential clearing" model. The main essence of this model is that market participants report electricity quantities and prices separately in the inter-provincial and intra-provincial markets. The inter-provincial market is prioritized for trading and clearing, with the clearing results used as the boundary for intra-provincial transactions. Finally, the intra-provincial market conducts its own clearing. This approach ensures fairness and transparency in transactions, while also preventing malicious competition among market participants and maintaining market stability.

In terms of operational institutions, the current focus primarily relies on provincial-level trading platforms for operations. These platforms help ensure supply-demand balance, system stability, and safe operation. However, this model presents certain market barriers and limited liquidity in inter-provincial trading. Therefore, further efforts are needed to ensure fairness, transparency, and openness in transactions. This includes refining market supervision mechanisms, safeguarding the rights of market participants, maintaining market order, and preventing abnormal market fluctuations.

3.3.2Basic Coupling Stage

As renewable energy becomes more widespread, market participants need to diversify further to accommodate a variety of entities such as microgrids and aggregated retailers. In addition to traditional thermal power generation units, power generation entities can participate in the market through flexible integrated combinations like wind-solar storage complementarity, reducing the need for deviation control. On the user side, distributed energy, conventional loads, and flexible loads can be aggregated through smart energy management systems to dynamically balance supply and demand, while also providing secure and stable services to the power system.

Simultaneously, the market needs to design more versatile pricing mechanisms to support the formulation of trading strategies for market participants. Flexible pricing types like segmented block pricing, exclusive block pricing, and associated block pricing can align better with the physical characteristics of equipment operation during market bidding, thus enhancing market efficiency. Such mechanisms can better support various types of market participants, further promoting the diversification and healthy development of the electricity market[11].

With the rapid development of renewable energy application technologies, the existing hierarchical market structure and operational coordination methods have become inadequate to meet the requirements for reliable grid operation. Therefore, adjustments are needed in the clearing model. Among these adjustments, a merged market clearing model that integrates inter-provincial and intra-provincial markets should be considered, taking into account the physical constraints of power sources and the grid, such as unit start-stop, ramping, transmission capacity, and other factors. This integration aims to ensure the reliable and flexible operation of the grid.

Additionally, it's important to explore the top-level design of electricity financial trading, the integration of the electricity market with carbon markets, green certificate markets, and more. This exploration can enhance the efficiency and stability of electricity market operations. By progressively promoting collaboration between markets nationwide, the operation of the electricity market will become more efficient and stable.

3.3.3Full Coupling Stage

In the context of the electricity market, a diverse competitive market structure has been established, accommodating various types of market participants, including integrated entities such as virtual power plants. The membership types within the market, such as power sources, grids, retail electricity companies, and end-users, are also quite diverse.

To meet the demands of market participants, continuous efforts are made to design, apply, and optimize more efficient and flexible bidding methods to support decision-making. Furthermore, regarding the clearing model, the "Unified Declaration of Total Electricity Quantity, Tight Coupling Clearing" model is adopted. In this model, market participants submit all information related to electricity quantity and price to the national trading platform. The national trading center then considers the overall system supply-demand balance and transmission capacity constraints for a comprehensive optimization clearing. Such a market operating mechanism can promote standardization and marketization of the electricity market, enhance transparency and reliability, and thereby stimulate the development and advancement of the electricity market[12].

4 Conclusion

In conclusion, research on the mechanisms of inter-provincial spot electricity markets and the decision-making systems for inter-provincial transactions holds significant theoretical and practical significance for advancing China's electricity market reform. Against the backdrop of rapid economic development in our country, the reform towards electricity market liberalization has become an inevitable trend. As a crucial component of this reform, the inter-provincial spot electricity market plays a pivotal role in rational resource allocation and market-oriented transactions of electricity.

To sum up, various regions have achieved certain accomplishments and experiences in the construction and operation of electricity spot markets. However, it is essential to recognize the existing issues and challenges, such as insufficiently developed market mechanisms, inadequate regulation, and limited diversity in transaction participants. Consequently, there is a need for further strengthening the research on inter-provincial spot market mechanisms and transaction decision-making systems. This involves deepening the understanding and mastery of market rules and regulatory mechanisms to drive the development of the electricity spot market towards a more robust, transparent, and equitable direction. By doing so, we can provide robust support for the smooth advancement of China's electricity market reform.

References

[1] Zou P, Chen Q, Xia Q, et al. Logical analysis of the construction of foreign electricity spot markets and its implications and suggestions for China. Power System Automation, 2014, 38(13): 18-27.

[2] K Ben. Joint Announcement of the National Development and Reform Commission and the National Energy Administration on the Pilot Work of Establishing Electricity Spot Market. Power and Energy, 2017, 38(05): 500.

[3] F Gu. Utilizing the Authorized Contract System to Promote the Construction of Electricity Spot Markets. Management of China Electric Power Enterprises, 2020, (16): 36-39.
[4] Interpretation of the "Inter-Provincial Electricity Spot Trading Rules (Trial)" [N]. State Grid News.
[5] Y Zhu. Taking a Solid Step in Building the Power Market System [N]. China Electric Power News.
[6] Yang X. China's Electricity Spot Market Ushers in New Progress[N]. China Energy News.
[7] Sung C C L H H H, Voltage Stability Assessment of a Campus DC Microgrid Implemented in Korea as a Blockchain-Based Power Transaction Testbed [J]. Energies, 2023, 16 (21):
[8] Sun D, Guan L, Hu C, et al. Design and Exploration of Inter-Provincial Electricity Spot Trading Mechanism. Power System Technology, 2022, 46(02): 421-429.
[9] Li Z, Ceng Y, Zhou C, et al. Analysis of Influencing Factors of Nodal Price Based on Simulation of Electricity Spot Market Clearing. Electrical Technology, 2020, 21(05): 41-47.
[10] Li C, Cao R, et al. Significant Future Needs and Key Technologies for Electricity Spot Market Trading Operations. Power System Automation:1-15[2023-10-08].http://kns.cnki.net/kcms/detail/32.1180.tp.20230720.1128.002.html.
[11] Paola M F M M.Measuring Switching Costs in the Italian Residential Electricity Market [J].The Energy Journal, 2024, 45(2): 189-208.
[12] Notice of the General Office of the People's Government of Shanxi Province on Printing and Distributing the Pilot Program for the Construction of Shanxi Provincial Power Market. Bulletin of the People's Government of Shanxi Province, 2017, (17): 9-25.