Application and Design of Technical Support System for High-Proportion Hydropower Spot Market

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Abstract: With the construction of electricity spot market entering the critical stage, the design and development of feasible and practical spot trading system has become a key task for implementing the application of large-scale medium and long-term trading plans. This study takes Yunnan high-proportion hydropower spot market as the engineering background. Considering the system architecture, the overall business function, and the integration implementation technology, we construct the spot system construction scheme in line with the hydropower-dominated provinces. Moreover, the integration technology of high proportion hydropower spot clearing model, the integration technology of large-scale complex optimization solver, and the whole process business visualization of spot clearing interaction technology are proposed and described. The developed system realizes the integrated functions of market subject declaration, transaction clearing, and security check and information release. The rationality, timeliness and practicability of the system are verified through the simulation applications of Yunnan electricity spot trading.

1 INTRODUCTION

In March 2015, the promulgation of Several Opinions of the CPC Central Committee and the State Council on Further Deepening the Power System Reform marked the beginning of a new round of power system reform in China With Document No. 9 as the top-level design, China's electricity market has achieved rapid development in the past five years, which can be roughly divided into two stages: the first stage is the construction of the medium and long-term market, mainly focusing on annual and monthly electricity trading. At present, each province has carried out the design and practice of medium and long-term trading rules and trading systems, and the trading scale has been expanding year by year(Shen, et al., 2022; Liu et al., 2019); the second stage is the construction of the spot power market. The first eight pilot projects, including Guangdong, Inner Mongolia, Zhejiang, Shanxi, Shandong, Fujian, Sichuan and Gansu, have prepared spot market rules that adapt to the characteristics of the province, and developed a spot technology support system. The simulation operation has been carried out in 2019. Yunnan, Jiangsu and other provinces will also start the trial operation of the spot electricity market(Jia, et al., 2022; Andrew et al., 2003).

Looking at the development of the global power market, due to different power supply structure, power grid structure, market characteristics, etc., there are still large differences between countries and regional electricity markets(Rudnick, et al., 2005; Wang et al., 2003; Zhang et al., 2020). It is difficult for China's power market to directly apply the theory and technical

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framework of foreign power markets. For the eight pilot provinces that have carried out the construction of electrification markets, market rules and system characteristics are also different. In addition to Sichuan, the power supply structure is generally dominated by thermal power. Taking Guangdong as an example, the spot market consists of a day-ahead market and a real-time market, which adopts a bilateral quotation and a centralized market model. The pricing mechanism of the power generation side market is the node price, and the user side is the weighted average of the node price; in terms of spot system, as the main power generators in the market are mainly coal power and gas power units, the complex nonlinear characteristics of hydropower units are not considered in the spot clearing model, and the system functions do not involve such businesses as matching the clearing results of upstream and downstream hydropower stations and hydraulic verification, it is difficult to directly apply to the high proportion of hydropower spot market. This paper focuses on the spot market in high proportion hydropower provinces. Taking Yunnan as an example, there are more than 180 large hydropower stations participating in the power balance, with an installed capacity of about 78200MW, accounting for more than 70% of the total installed capacity of power generation in the whole network(Shen et al., 2019). The electricity market with such a large proportion of hydropower is greatly different from most domestic and foreign power markets, which are dominated by thermal power, gas power. Due to the randomness of runoff, uneven distribution of time and space, the coupling characteristics of hydropower and electricity at the upstream and downstream of the cascade lead to greater complexity and difficulty in clearing the spot system, especially in the construction of the spot technical support system, how to solve a series of theoretical and technical problems such as dynamic construction and integration of the hydropower spot clearing model, efficient solution of large-scale complex systems and seamless integration of optimized software, and the realization and interaction of the integrated business of declaration clearing verification release, it will directly affect the smooth completion and real implementation of Yunnan and other electricity spot markets, and it is urgent to make theoretical and technological innovation.

This paper mainly focuses on the technical level. Focusing on the actual project of Yunnan's high proportion hydropower spot market, from the three aspects of the overall system architecture, overall business functions, and integrated implementation technology, it constructs a spot system construction scheme that conforms to the hydropower dominated provinces, and puts forward the integration technology of the high proportion hydropower spot delivery model, the integration technology of large-scale complex optimization solver, and the visualized dynamic interaction technology of the whole process of spot delivery, it realizes the integration functions of market entity declaration, transaction clearing, security check, information release, etc. The timeliness, rationality and practicability of the system are verified through the simulation application of Yunnan electric power spot transaction.

2 THE WHOLE SYSTEM FRAMEWORK

The power spot market technical support system is faced with complex business requirements such as multiple market entities, large amount of data interaction, and high difficulty in business integration, especially for the unique operation business and calculation requirements of the hydropower system, which requires top-level design in terms of data storage and service with different characteristics such as water regime, power, electricity price, clearing model and algorithm construction, business functions, based on the analysis of the actual business needs of spot electricity trading in the high proportion hydropower market and the mature enterprise platform technology, the overall structure of the spot market technical support system based on tiered services is constructed. See Figure 1 for details.

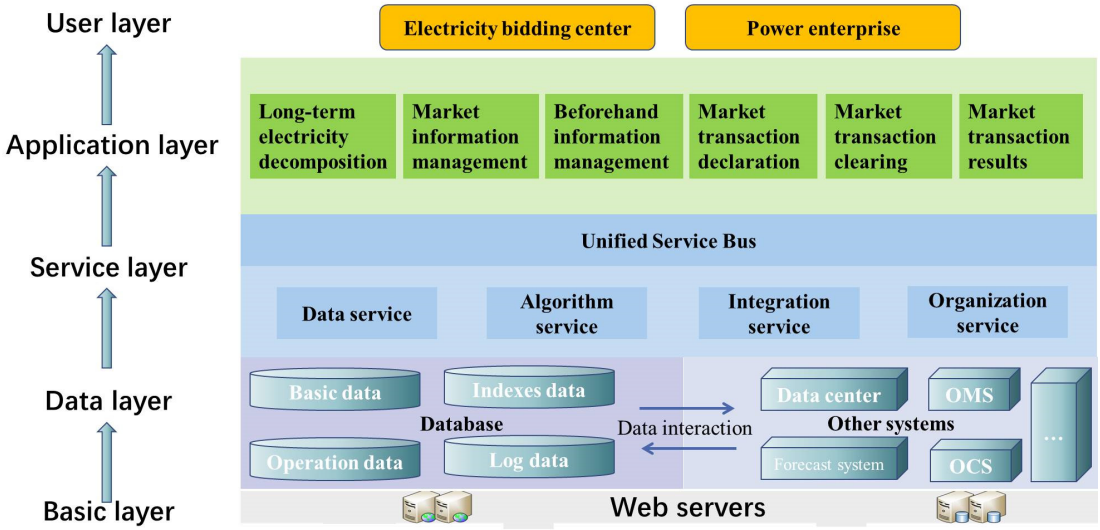

Figure 1: Overall framework of technical support system for high proportion hydropower spot market.

The overall architecture of the system is composed of the basic support layer, data storage and interaction layer, service layer, application layer and user layer, and all layers cooperate and authenticate with each other. Among them, the basic support layer is responsible for the hardware and software for the stable operation of the entire system, providing a stable operating environment for platform construction, and ensuring the high availability of the system by introducing node, storage, distributed computing and other load balancing technologies; the data storage and interaction layer is responsible for the interaction and storage of internal and external data in the system WEBSERVICE, JSON, FTP and other technologies to achieve seamless real-time connection with the data centre. At the same time, a distributed temporal database and a high-performance memory database for massive hydrological data storage and high concurrent access have been built to ensure system stability and computing efficiency; the service layer is responsible for all services of the entire spot system, including data services, algorithm services, integration services and organization services, including core services such as hydraulic check calculation, unit combination optimization and spot clearing model for high proportion of hydropower systems. It realizes unified management of all businesses based on the service bus to ensure loose coupling between applications; the application layer relies on various services provided by the service layer to realize the main business functions of the spot electricity market according to the business process, including the medium and long-term transaction electricity decomposition, market information management, information management, market transaction declaration, clearing, and transaction results display and analysis, among which the monthly electricity decomposition and daily curve decomposition mainly consider the incoming water, water level, and different varieties of transaction results to achieve the refined coordination calculation of cascade hydropower stations, the declaration data verification realizes the automatic verification of the power generation boundaries such as the water level, flow and output of hydropower plants, the hydraulic constraint verification and spot clearing can simultaneously consider the nonlinear hydraulic characteristics of more than 100 hydropower stations and ensure the accurate matching of the electricity and water volume of upstream and downstream hydropower stations through iterative optimization; the user layer is a visual operation interface presented to market members and an important entrance for the system to perform various operations.

3 COMPONENTS OF SPOT MARKET SYSTEM

Guided by the actual business needs of the high proportion of hydropower spot market system, the corresponding medium and long-term and spot market collaborative business system is designed,

including market bidding component, application data integration management and analysis component.

3.1 Market Bidding Component

This component involves core production businesses such as the decomposition of medium and long-term plans and the integration of the whole process of spot transactions, which can meet the connection between medium and long-term transactions and the spot market, as well as the preparation requirements of the day ahead transaction plan on the power generation side. The medium and long-term plan decomposition provides multiple strategies for decomposing monthly electricity to daily and daily electricity to curve, covering multiple market entities such as power generation enterprises and wholesale users, as well as multiple transaction varieties such as bilateral negotiation, to ensure an orderly connection with spot transactions; Different from the market dominated by thermal power, the high proportion hydropower spot system needs to comprehensively consider the predicted inflow process of the reservoir, as well as complex boundary conditions such as reservoir water level, power generation flow, output limit, water balance equation in Multi-scale trading power decomposition, so as to achieve high-quality peak shaving of hydropower and efficient utilization of hydropower resources while meeting the control goal of transaction results. The spot market is carried out in an orderly manner according to the business processes of market entity declaration, transaction clearing, security check and information release, realizing the full business integration function of spot transactions. For market operation entities such as trading centres, they can control and manage the spot market process according to time nodes in market management, set the declaration parameters of each market entity in the declaration module of market entities to flexibly configure the behaviour of market entities, and integrate the cascade electricity linkage control spot clearing method and complex hydraulic constraint check and adjustment strategy that meet the optimization of large-scale hydropower stations in the transaction clearing module, and integrate DC power flow check AC power flow check and other technologies have solved the problem of spot clearing efficiency under the constraint of time-space coupling of water power and electricity, and avoided the potential power shortage, water abandonment and other prominent problems in the result of power generation mismatch of cascade hydropower stations.

3.2 Application Data Integration and Analysis Service Component

For high proportion hydropower system, the data sources for the connection between medium and long-term spot transactions are extremely complex, including water level at multiple time scales such as year, month, day, hour and 15 minutes, inflow flow, generation flow, waste water flow, two-dimensional water level storage capacity curve, tail water level discharge curve, three-dimensional unit HNQ curve and other complex data different from the main thermal power market, involving water dispatching automation system, runoff prediction system, power trading system， energy-saving power generation dispatching system, the interactive data presents typical heterogeneous and polymorphic characteristics, and the data processing is very difficult. Therefore, according to the logical relationship, category, characteristics and format of the stored data, a unified data description rule is established. Based on this, the database mapping interaction function, chart visualization processing function, and real-time calculation and check analysis service function of water regime data oriented to the transaction clearing process are realized for different businesses in different time scales, meeting the dynamic construction of hydropower station dispatching and grid boundary constraint processing requirements in actual projects. This part of functions includes cross application collection of heterogeneous polymorphic data, basic data management, operation and indicator data statistics, and log data monitoring, which can meet the requirements of medium - and long-term plan decomposition in actual projects and dynamic construction of system constraint processing in the spot clearing model, and provide important data support for the development of core businesses in the medium - and long-term and spot markets.

4 KEY TECHNOLOGIES

4.1 Integration Technology of High Proportion Hydropower Spot Clearing Model

As the core business of the clearing link of spot electricity trading, the spot clearing model needs to

consider the automatic construction technology of large-scale power plants and their complex constraints and the model adaptive technology to adapt to different trading rules and needs, especially for the high proportion of hydropower spot market, the differences in the geographical location, regulation performance, installed capacity, incoming water size, water level status, unit characteristics of the cascade hydropower stations, it will have a great impact on model construction and adaptability. To this end, the integration technology of high proportion hydropower spot clearing model is proposed to solve the problem of hydropower spot market clearing model integration from two aspects: the automatic description and integration of model boundary conditions, especially the characteristics of hydropower system, and the target and constraint configurable component integration library. See the following for the detailed integration technology。

1）Automatic description and fusion of hydropower system characteristics

The main difference between hydropower system and thermal power system is that they involve many complex nonlinear hydraulic characteristics and are uncertain. There are also large differences between river basins and upstream and downstream power stations. Especially for the high proportion of hydropower market, spot clearing modelling is required to realize the automatic description and integration of these characteristics. Therefore, a directed graph description technology for the relative spatial position of cascade hydropower stations is proposed. By constructing the directed graph cascade topology structure, the topology and time sequence relationship between hydropower stations can be automatically analysed to adapt to the differences and changes in the composition structure of hydropower stations in different basins; The hydraulic condition analysis and fusion technology based on the automatic transaction mechanism is proposed, which defines the characteristics, frequency, mode and other transaction rules of incoming water, output, water level, flow and other data, and combined with JAVA multithreading technology, the automatic timing processing of different scales and different data businesses is realized, and the data encoding and matching technology is used to automatically integrate contract type data, which significantly improves the analysis accuracy of complex hydraulic data; The automatic modelling technology for the restricted area of complex units of SCUC and SCED high head large capacity units is proposed. The irregular multi restricted operation area constraints of southwest giant hydropower units can be automatically incorporated into the spot clearing model by using polygonal subdivision linearization approximation modelling, so as to avoid unreasonable transaction results.

2）Hydroelectric target and constraint configurable component integration library

The dynamic changes of spot market clearing rules, dispatching conditions of hydropower system and operation demand put forward new requirements for the construction of clearing model, and it is necessary to build an extensible component integration library to cope with the flexible changes of clearing rules. The clearing model is divided into two parts: objective function and constraint condition, and a flexible configuration component library are constructed respectively. Each component library can be freely combined to form an extensible integration library. The objective function library is composed of various objective functions facing different business needs, including the optimal cost category, the largest clean energy consumption category, such as the largest hydropower consumption, the smallest risk category, such as the minimum risk of abandoned water, the minimum risk of power shortage, the constraint library involves different classification standards, including classification by power type, classification by constraint characteristics, etc.

4.2 Integrated Technology of Large-Scale Complex Optimization Algorithm

The solution of the clearing model in the spot electricity market itself is a complex optimization problem, especially in the high proportion hydropower system, which is recognized as one of the most complex systems in the world. Due to the nonlinearity of hydropower itself and the coupling constraints between the cascades, the clearing problem has the characteristics of non-convex, nonlinear, discrete, high-dimensional, and is facing outstanding difficulties in solving. The traditional solution methods include dynamic programming methods, intelligent optimization algorithms, etc. However, as the scale of the problem increases, the control conditions and constraints of the model increase significantly, and the traditional dynamic programming methods have serious "dimension disaster" problem; Although intelligent optimization algorithms such as genetic algorithm and simulated

annealing algorithm can flexibly deal with various nonlinear constraints, and there is no dimension disaster problem, the algorithm is essentially a random optimization, which cannot guarantee the global optimal solution, and has insufficient stability, which is not conducive to the traceability of results; The mathematical planning method model is flexible in construction, which can ensure the stability of the solution. It is currently a common method to solve the problem of large-scale spot clearing.

In order to ensure the efficient solution of large-scale complex clearing model of high proportion hydropower system and improve the automation of clearing modelling and solution of spot system, a large-scale complex optimization solver integration technology is proposed by integrating multiple optimization solvers into the spot system. The core idea of this technology is based on the standard interface program provided by the optimization solver, using Java API modelling standardization tool software, to automatically realize the docking with the solver, specifically through the following steps: first, load the specified optimization solution interface call package to the specified project path, and build the solution environment; second, analyse the format specification of the designated algorithm, and use Java programming language to express the cash clearing mathematical model as the optimization model that the solver can recognize according to the format specification requirements; third, call the optimization solver solution engine to solve the model, and use the query function to view the model solution results. The integrated technology of complex optimization algorithm is adopted to integrate many different optimization algorithms into the spot system, which can effectively realize the automatic construction and solution of the clearing model, and greatly improve the automatic clearing modelling capability and efficiency of the spot system.

5 APPLICATION

5.1 Practical Engineering

Yunnan Power Grid is a typical high-proportion renewable energy grid dominated by hydropower. It is the main delivery end of China's West East Power Transmission Project. In the face of large-scale clean energy export, hydropower is subject to the impact of uncertain runoff in the process of consumption and spot trading, and the close hydropower linkage between the terrace hydropower plants. At the same time, grid security constraints limit the flexibility of bidding, increasing the difficulty of market clearing; In addition, core businesses such as medium and long-term connection with spot transactions involve heterogeneous and polymorphic data collection, storage, query, processing and analysis, which bring great challenges to the development of the spot market.

Based on the platform architecture and key technologies of a high proportion of hydropower spot market, the core business of medium and long-term plan decomposition and spot trading is realized. Taking the actual project in Yunnan as an example, the whole process of core business in the spot market has been realized by using this platform.

5.2 Application Analysis of Technical Support in Spot Market

The functions of the spot market involve the declaration of market entities, the clearing of transactions, the security check and the release of results. Among them, the spot market clearing model is the core of the optimal allocation of resources. It needs to combine the volume and price information declared by market entities, grid boundary constraints and security constraints, hydropower and power connection of cascade hydropower stations, and at the same time consider the information such as the runoff forecast of hydropower stations to achieve the optimization goal of maximizing the social welfare of the whole network, that is, minimizing the power purchase cost.

In the day ahead spot verification, the spot market system integration technology was used to carry out the core business of market entity declaration, day ahead clearing, verification and result release. As shown in Figure 2, market entities can declare the time and electricity price curve of the next day; after the declaration of each market entity is completed, carry out the day ahead clearing and verification, as shown in Figure 3. Under the hydraulic constraints of cascade hydropower stations and the grid security constraints, the day ahead clearing results meet the requirements of the whole network load balance, and the system takes about 5 minutes to solve, meeting the timeliness requirements; as shown in Figure 4, the statistics of multiple clearing results, such as units, nodes and cross section channels, are also provided to facilitate the trading centre to query the clearing results.

In the case study, two cases are presented. The first case focuses on influence of navigation constraints on cascaded hydropower system operations. The last case concerns the influence degree of annual inflow on operation results under navigation constraints.

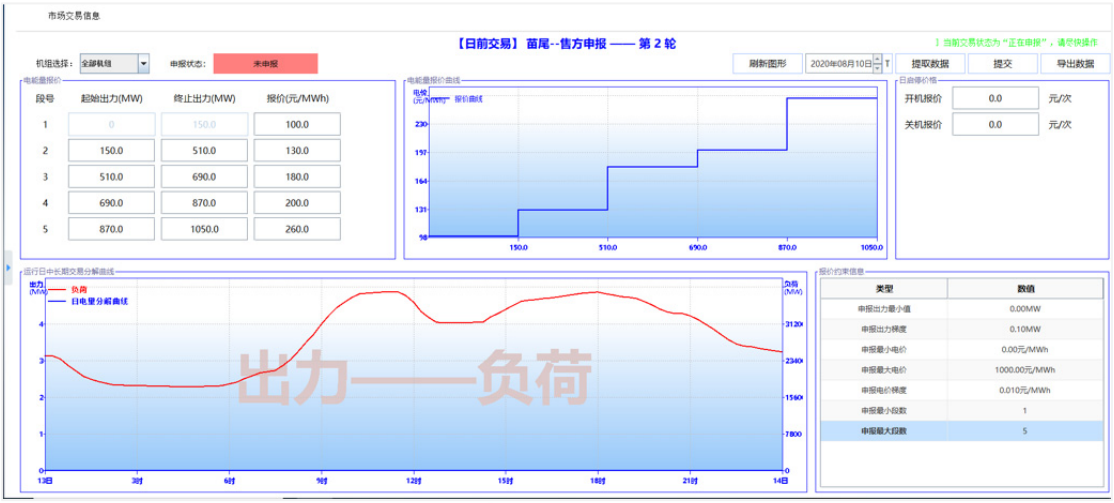

Figure 2: Typical interface of market subject declaration.

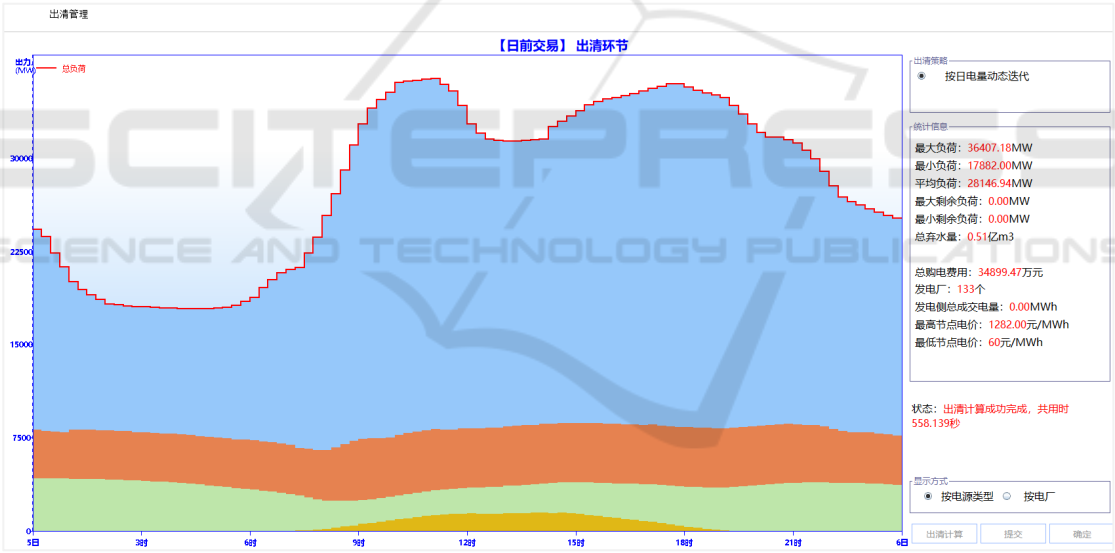

Figure 3: Typical interface of day-ahead market clearing.

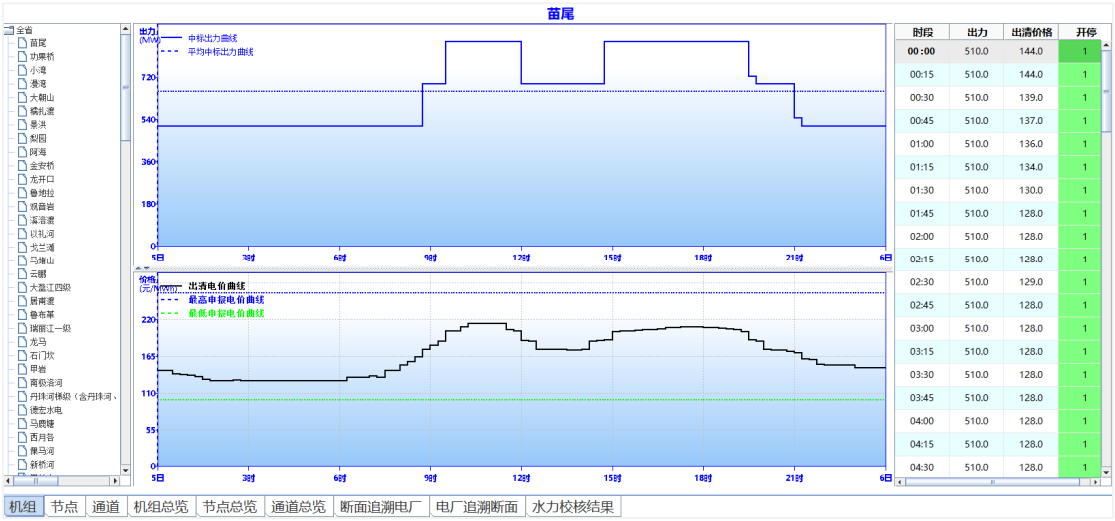

Figure 4: Typical interface of market clearing results.

6 CONCLUSION

The reform of China's power market has entered a deep-water area. As the energy base of "Power Transmission from West to East", some high-proportion hydropower provinces in southwest China, such as Yunnan, Sichuan, Guizhou, Guangxi, Chongqing and Tibet, have important characteristics and representativeness in their spot market construction. However, they also face many theoretical and technical challenges that have not been encountered in the spot market dominated by thermal power. It is of great practical significance to build a spot trading technical support system suitable for these high-proportion hydropower markets. Combined with the construction and practice of Yunnan's spot electricity verification system, this study gives the overall technical architecture and main components of the system in detail, systematically expounds the hydropower spot clearing model and integration technology, optimization algorithm integration technology. Finally, the simulation verification of the spot electricity clearing through the 96-point actual operation data of Yunnan Power Grid for many days is carried out. The results show that the constructed technical support system can converge in a short time, and obtain the day-ahead clearing operation schedules.

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