Review on Medium and Long-Term Operation Strategy of Hydropower-Enriched Power Grid in Electricity Market

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Abstract: The new round of power market reform brings great challenges to the operation of Chinese power grid. For the power grid dominated by hydropower, how to effectively carry out market trading and consumption of large and small hydropower, reduce the impact of uncertain water inflow on market returns, and ensure the stable operation of the power grid under the market mechanism are all new challenges. This paper focuses on the key issues such as the potential market manipulation ability of giant cascade hydropower stations under the electric power market environment, and the income analysis of large-scale and small hydropower stations participating in the electric power market. It compares and analyzes the advanced management experience at home and abroad, and introduces the research contents and trends at home and abroad from three aspects: hydropower enrichment in the electric power market, cascade hydropower research, and grid operation of small hydropower stations.

1 INTRODUCTION

China is the country with the most abundant water energy resources in the world, ranking the first in the world in total volume. The theoretical reserves of hydropower resources are about 694 million kW, and the annual annual generating capacity is about 6 trillion kWh. The exploitable capacity of the technology is about 540 million kW, and the annual generating capacity is about 2.5 trillion kWh. The economic exploitable capacity is about 402 million kW, and the annual generating capacity is about 1.75 trillion kWh (Cheng, 2016; Deepak, 2015; Wu, 2014). In the past 20 years, hydropower has developed rapidly. The installed capacity of hydropower in China exceeded 100 million kW, 200 million kW and 300 million kW respectively in 2004, 2010 and 2014.However, the distribution of hydropower resources in China is characterized by uneven distribution of time and space, high enrichment degree of hydropower and obvious regional differences, among which southwest China is the most concentrated area of hydropower resources. The exploable capacity of hydropower technology in Sichuan, Xizang, Yunnan, Guangxi, Guizhou and Chongqing was 414 million kW, accounting for 76.6% of the national total (Jean-Michel, 2014; North American Electric Reliability Cooperation, 2019; Cui, 2013; Ding, 2013).

Hydropower enrichment grid refers to the power grid with a large proportion of hydropower installed capacity and generating capacity. In the process of power market reform, hydropower enrichment grid not only needs to solve market regulation, clean energy marketization, stable operation of power grid and other power market connectivity issues. At the same time, it is necessary to focus on the characteristics of hydropower enrichment grid, such as the market power of giant cascade hydropower stations, the operation status of large and small hydropower stations, and the operation characteristics of large and small hydropower stations connected to the grid. Therefore, hydropower enrichment network will face unprecedented new challenges in the process of power market reform

This paper focuses on the key scientific issue of the operation strategy of hydropower enrichment grid in the electricity market environment. Compared with the advanced experience at home and abroad, this paper analyzes and summarizes the potential market manipulation ability of the huge cascade hydropower station group, the income

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analysis of the participation of large-scale and small hydropower in the electricity market, and the threat of the deviation of trading plan to the stable operation of the power grid.

2 FOCUS AND HYDROPOWER ENRICHMENT AREA POWER MARKET

Foreign power market reform in the 1970s had begun to emerge, but it was not until 1989 that the United Kingdom promulgated the "Electricity Law" in the world set off a wave of power industry reform. Its core is to break the monopoly, privatize the power industry and introduce market competition. Since then, Norway, the United States, Brazil, European Union countries, Canada and Australia have also started power market reform, aiming to use the competition of the free market to guide the power industry to improve efficiency and reduce electricity prices and operating costs. After nearly 30 years of development, foreign electricity market has been basically mature, mainly reflected in the market structure, trading mode, regulatory mechanism and auxiliary services and so on. In this paper, the development and construction process and main operation effects of foreign power markets in key and hydropower enrichment regions are briefly reviewed:

The United States issued the Energy Policy Act in 1992, marking the start of electricity market reform. In 1996, the Federal Energy Regulatory Commission (FERC) issued No. 888 and No. 889, requiring power companies to open the transmission grid. From 2002, there was a wave of reform in the states of the United States. Currently, there are approximately 10 regional electricity markets in the United States, seven of which are regional transmission organizations or independent system operators (Operating regional wholesale electricity markets: New England ISO, New York ISO, Texas ISO, California ISO, Central ISO and PJM's RTO, Southwest RTO) (Su, 2014; Han, 2019; Xu, 2018). States and regions in the United States have different reform models, and there are also multiple models of power enterprises, including traditional vertically integrated companies, power supply companies mainly responsible for regional distribution and power supply, and independent power generation companies .Literature (Marko, 2014) systematically reviewed and analyzed the electricity market reform in the United States in the past 20 years, and proposed that the restructuring of the American electric power industry should focus on three aspects: generation, transmission and sale of electricity: the promotion of generation side competition, the change of generation ownership and profit model, and the increasing share of independent generators; Promote the opening of the power sale side, more users get the power sale option, but the power sale service innovation technology conditions and market structure and other factors are limited; Promote fair opening up of power grids, and ensure fair opening up of power grids to third parties by strengthening supervision and establishing ISO and RTO; After the reform, wholesale electricity price has not been continuously reduced, and the impact of fuel cost, technological progress and other factors on electricity price is greater than that of the reform.

The European Union (EU) issued the Electricity Market Reform Act in 1996, which opened the user's choice and promoted the establishment of the EU's unified electricity market. Then in 2003, the Second Law of Electricity Market Reform was issued, which strengthened the efforts to promote the construction of EU unified electricity market. Under the overall framework of the EU, member states have chosen different market-oriented reform models according to their own actual conditions. The UK electricity market has undergone two important reforms (Zhou, 2015; Ding, 2014; Lu, 2016). The first is the transformation from POOL mode, which is the mandatory competitive market of full power generation through bidding, to NETA, which is the trading mechanism dominated by bilateral transactions with the voluntary participation of market subjects. The second was the transition from NETA to BETTA, a nationwide unified competitive electricity market. In 2013, the UK started to implement a new round of reforms, focusing on the introduction of a mechanism combining fixed electricity price and CFD for low-carbon energy, the establishment of carbon emission performance standards for new units, and the establishment of capacity markets. France has introduced competition on both the generation side and the sales side while keeping its vertically integrated structure intact. In the power generation side, there are 5 large power generation companies, among which the market share of EDF reaches more than 90% (Kashif, 2014). The power market trading is mainly bilateral contract trading, and the day ahead spot trading is mainly organized and carried out by EPEX power spot Exchange. German electricity market reform is relatively slow, after the establishment of electricity market supervision department in 2004, the pace of electricity market reform has been accelerated. At present its electricity futures trading and day-ahead trading is mainly carried out by Europe's largest electricity exchange (EEX). In addition to the member states establishing their own electricity markets, the EU has gradually realized the joint trading of multi-country and multi-regional markets, and the market mechanism based on the unified market rules to realize joint clearing has been gradually established. In 2006, the joint market of France, Belgium and the Netherlands began to operate; In 2008 Germany and Denmark began joint trading of day-ahead electricity markets; In 2010, the Central and Western European regions achieved market integration.

Australia is an early country to carry out electricity market reform. In 1990, it split the four links of vertical integration of power generation, transmission, distribution and sales, and introduced competition in the power generation side and the power sales side. There are currently two electricity markets in Australia: the National Electricity Market (NEM) and the Western Australian Electricity Market. NEM is the main electricity consumption region in Australia, which is divided into electricity wholesale market and electricity finance market. The wholesale electricity market adopts the POOL model, and the Australian Energy Market Operator (AEM0) is responsible for centralized trading and scheduling. All electricity trading must be conducted through AEMO. At the same time, in order to reduce the risk of price fluctuation in the wholesale power market, market players can also choose to participate in the power financial market and conduct transactions in the government-approved stock and futures exchanges. As part of its economic liberalization policy, New Zealand established the Electricity Corporation of New Zealand (ECNZ) in 1987 to operate the electricity industry in a market-oriented manner. In 1998, New Zealand promulgated the Electricity Industry Reform Act 1998, which required the separation of property rights between power generation and sales and distribution box sales, so as to realize the independent operation of each link of power generation, transmission, distribution and sales, and introduce competition in the power generation and sales links. In 2010, New Zealand promulgated the Electricity Industry Act 2010.Integrated distribution operations are allowed, provided it is clear that the distribution business is subject to strict regulation.

In 2002, China promulgated the "Electric Power System Reform Plan" for the purpose of "separating plant networks and bidding to access the Internet, breaking monopoly and introducing competition". The former State Power Company was divided into five power generation groups: China Huaneng Group Corporation, China Datang Group Corporation, China Huadian Group Corporation, China Guodian Group Corporation and China Power Investment Corporation; And two major power grid companies: State Grid Corp. and China Southern Power Grid Co (Zhang, 2008). In 2015, Several Opinions on Further Deepening the Reform of the Electric Power System were released, in which the focus and path of reform were put forward as follows: On the basis of further improving the separation of government functions and enterprises, the separation of factories and networks, and the separation of main and auxiliary components, in accordance with the institutional structure of controlling the middle and liberalizing the two ends, we will in an orderly manner liberalize the price of electricity for competitive links other than transmission and distribution, open the distribution and sale of electricity to private capital in an orderly manner, and liberalize power generation plans other than those for public welfare and regulatory purposes in an orderly manner. Promote the relative independence of trading institutions, standardized operation; Continue to deepen research on regional power grid construction and transmission and distribution system suitable for national conditions; We will further strengthen government supervision, overall planning, and safe, efficient operation and reliable supply of electricity.

3 RESEARCH ON CASCADE HYDROPOWER STATION UNDER ELECTRICITY MARKET ENVIRONMENT

In the electric power market environment, the operation mode and goal of cascade hydropower station have changed from the operation mode of cooperating with the power grid dispatching organization to meet the system load demand and ensure the safety and stability of the power grid to the operation mode of pursuing the maximum profit in the market environment. With the gradual advancement of domestic and foreign power system reform, many scholars have studied the bidding and operation of hydropower stations and cascade hydropower stations in the market.Literature (Liu, 2015) took autonomous dispatching hydropower companies as the object and used 0-1 mixed integer programming to study their bidding strategies and operation problems in the power pool model-day-ahead market. Yang Literature (Hu, 2014) considered the unit flow, output constraints, feed-in price and other conditions of cascade hydropower station under the power market conditions, which made the scheduling problem more complicated. They used diplebody genetic algorithm to study the economic operation problem of the power generation company with cascade hydropower station with the greatest benefits in the market. Literature (Cheng, 2014) divided the hydro-thermal hybrid power system into two independent bidding subsets in consideration of the influence of hydropower price and the start-up and shutdown costs of hydropower units. Within each subset, the bidding was conducted according to the principle of the lowest power purchase cost, and the power output of hydropower was optimized by the method of simultaneous segment adjustment. According to the characteristics of hydropower plants, Zhao Literature (Daniel, 2014) respectively considered the game between hydropower plants and thermal power plants, the game between hydropower plants and the game of peak-regulating power plants; by estimating the bidding behavior of other power plants, they established an online bidding game model for hydropower plants to provide guidance for the management of hydropower plants.Literature (Douglas, 2013) proposed a bidding online model for hydropower companies applicable to different market environments in spot trading, taking the bidding coefficient as a variable parameter to reflect the interrelation between the bidding coefficient and predetermined optimization objectives. The model analysis proves that under the condition that the bidding strategy does not affect the clearing result, the maximum profit can be obtained and the total operating cost of the system can be minimum.Literature (Erik, 2015) adopted the probability distribution to simulate the quotation strategy of power producers, used the Monte Carlo method to conduct random simulation of the power market clearing process, and considered the factors of different generation costs of each cascade power station in the maximum benefit model, proposed the bidding operation strategy of cascade hydropower station under market bidding, and built the optimal scheduling model of cascade hydropower station under market bidding. Literature (Zhang, 2013), starting from the economic and technical characteristics of cascade hydropower station, established a stochastic expected value bidding model of cascade hydropower station aiming at the overall income maximization, considering the uncertain factors such as electricity energy price, reserve price and standby dispatching.

In the study of the operation of cascade hydropower station in the electricity market environment, the optimization scheduling analysis of cascade hydropower station itself is a typical large-scale high-intensity, non-convex nonlinear discontinuous problem mathematically. According to the different optimization methods, the solution can be divided into two categories: mathematical programming method and intelligent algorithm. Mathematical planning method is an optimization method based on the classical mathematical optimization principle, and it is also the earliest classical method applied in the field of optimal scheduling of hydropower stations. Its advantages lie in the strict mathematical derivation process, and the application of the method is easy to understand. Common mathematical programming methods include: linear programming; Nonlinear programming, including: continuous linear programming, continuous quadratic programming, generalized reduced gradient method, etc.; Mixed integer programming; Dynamic programming, dynamic programming improvement methods mainly include: incremental dynamic programming, discrete differential dynamic programming, dynamic programming successive approximation and stepwise optimization algorithm; Network flow planning, Lagrange relaxation and large system decomposition and coordination. Intelligent algorithm based on biomimetic, according to experience or natural evolution phenomenon simulation derived from the emerging algorithm, is born with the rise of modern computer technology and artificial intelligence in the 1990s.With the further development of computer technology, different kinds of intelligent algorithms have provided new ideas for domestic and foreign scholars to solve the optimization problem of large-scale hydropower stations. The widely used intelligent algorithms are: genetic algorithm, particle swarm optimization algorithm, differential evolution algorithm, hybrid optimization algorithm, ant colony algorithm and simulated annealing algorithm.

4 RESEARCH ON THE OPERATION OF LARGE-SCALE SMALL HYDROPOWER CONNECTED TO THE GRID

As an important part of clean and renewable energy, small hydropower is a priority project funded by the Clean Energy Development Mechanism (CDM). In recent years, it has attracted much attention due to its rapid development. At present, researchers in various countries have carried out relevant studies on the development status and problems of small hydropower in their own countries and regions: Literature (Milena, 2017) conducted an in-depth discussion on the development and forms of small hydropower in Turkey, and Literature (Tim, 2012) analyzed the development of small hydropower in India.

Due to various reasons such as construction and development history, small hydropower has been in the state of "light tube reconstruction" for a long time in our country, and there are many problems in its grid-connected operation (Su, 2014): 1) Small hydropower construction away from load center;2) The operation equipment is old and inefficient;3) The construction scale of small hydropower is huge;4) Output seasonality is obvious and fluctuation is high;5) Poor communication facilities and low level of management personnel;6) Backward management mechanism;7) Lack of effective legislative mechanism support. After the implementation of energy-saving power generation dispatching, China Southern Power Grid, which has a large proportion of installed small hydropower, successively issued a series of policies to improve the decision-making level of small hydropower dispatching. During this period, domestic scholars conducted relevant studies on the grid-connected operation of large-scale small hydropower. In terms of output prediction of small hydropower groups, Literature (Olayinka, 2011) proposed a FC-BP prediction method for short-term power generation capacity of small hydropower based on the combination of fuzzy clustering and BP neural network. Sun Yongjun et al. proposed a two-stage prediction method combining weighted Markov chain and GM (1,1) model. With BP neural network prediction model as the method, Liu Benxi et al. adopted partial mutual information method to screen the forecast factors that significantly affect the power generation capacity of small hydropower, and combined with the weather forecast information of the weather prediction system as the input, to achieve the power generation capacity prediction of small hydropower in data-poor areas. Literature (Newman, 2011) made a comprehensive analysis and discussion on the existing problems and market demand of small hydropower development in our country. Literature (David, 2011) proposed a multi-stage sectional control load distribution method for large-scale small hydropower groups, standardized the day-ahead scheduling plan formulation process of small hydropower, abandoned the traditional mode of unilateral planning by dispatching agencies, and implemented hierarchical generation plans according to the scheduling relationship of small hydropower. Literature (Juan, 2010) put forward a short-term coordinated optimization dispatching model of maximum expected capacity of large and small hydropower. Taking small hydropower in subdivision as a whole, according to the deviation between small hydropower plan and actual output, fuzzy clustering was adopted to construct small hydropower output scenario, and heuristic search and correlation search methods were applied to solve the problem. Literature (Yuan, 2010) established an expected peak regulation model for the joint operation of multi-scenario small hydropower stations and large and medium-sized hydropower stations. Through similarity analysis, the predicted output of the current small hydropower stations was identified as the category of forecast scenarios, and then the probability distribution of actual scenarios under the current forecast scenario was obtained.

5 CONCLUSION

For the power grid dominated by hydropower, how to effectively carry out market trading and consumption of large and small hydropower and how to reduce the impact of uncertain water inflow on market returns are new challenges. This paper compares and analyzes the advanced management experience at home and abroad, and introduces the research contents and trends at home and abroad from three aspects: hydropower enrichment power market, cascade hydropower station research, small hydropower grid operation, which will bring reasonable reference for China's electric power reform.

Along with the further deepening of the electric power market reform of our country, it will be the hot issue now and in the future how to explore the effective theoretical method and technical measure from the theory and practice according to the actual situation of our different regions electric power market. Although some research achievements have been made, the construction of Chinese electric power market is still in the initial stage. With the gradual improvement of market rules and the rapid development of trading business, the operation strategy and mode of hydropower enrichment grid under the environment of electric power market still need to be further studied.

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