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Cascade reservoir management model for Wujiang River Basin

1 An overview of cascade reservoirs in a river basin

Wujiang River Basin is located at the edge of Yunnan Guizhou Plateau and Sichuan Basin in China. Its river runoff is abundant, stable, with less sediment content, concentrated natural drop of the river course, superior topography and geology of dam site, relatively small engineering quantity and reservoir inundation loss, theoretical dry water energy reserve of 10430MW, and annual average power generation of about 50.8 billion kW.H. Wujiang River is one of the thirteen largest hydropower bases in China. It has hydropower resources, good cascade regulation performance, excellent technical and economic indicators, and obvious location advantages.

The main power stations planned in the basin have been fully developed, with a total installed capacity of 12782MW, mainly developed and operated by five different owners. Seven cascade hydropower stations located in the mainstream of Guizhou and two cascade hydropower stations in Qingshui River, a tributary of Guizhou, belong to Guizhou Wujiang Hydropower Development Co., Ltd. (referred to as Wujiang company), with an installed capacity of 8695MW, accounting for 68% of the total installed capacity of Wujiang River Basin. The three power stations located in the mainstream of Chongqing belong to the Chongqing Branch of Datang International Power Generation Co., Ltd. (referred to as Datang Chongqing Branch), with an installed capacity of 2920MW, accounting for 23%.

2 Watershed management mode and current situation

2.1 Management mode and current situation

2.1.1 Dispatching management

Cascade reservoirs in Wujiang River Basin mainly focus on power generation, followed by flood control and shipping. Generally, power dispatching shall be subject to flood control and shipping dispatching, and shipping dispatching shall be subject to flood control dispatching. Wujiang River is a tributary of the Yangtze River. When there is a basin flood in Wujiang River, the Yangtze River Water Resources Commission, the competent department for flood control in the Yangtze River Basin, will coordinate and dispatch as a whole.

Flood control operation: considering the reservoir capacity and geographical location, most reservoirs in Wujiang River Basin do not undertake flood control tasks. The flood control reservoirs are Hongjiadu, a multi-year regulating leading reservoir, Wujiangdu, a seasonal regulating water-saving reservoir, Goupitan, a daily regulating reservoir, Silin and Shatuo, and Pengshui, a seasonal regulating reservoir.

Power generation dispatching: in Guizhou, except for the Goupitan power station, which belongs to the South China power grid, the other power stations belong to the central tune in Guizhou province. The power supply of the Goupitan power station is sent to Guangdong, and other power stations are retained locally in Guizhou. The primary and branch water power stations located in Chongqing in the lower reaches of Wujiang River Basin belong to Chongqing Municipal dispatching. However, the Guizhou intermediate tune belongs to the south net Power Grid Corp, and the Chongqing City tone belongs to the national Power Grid Corp, which is the two different power grid systems.

Shipping dispatching: the channel traffic volume of the Wujiang River Basin is mainly concentrated in the lower reaches of Chongqing. Pengshui Yinpan cascade reservoirs at the end of the basin consider shipping dispatching, and the navigation dispatching unit is Chongqing port and Shipping Bureau.

2.1.2 Upstream and downstream hydropower management and operation coordination

Pengshui Yinpan cascade reservoir of Datang Chongqing branch is located at the end of the basin, and the upstream reservoir belongs to Wujiang company. As the planning rigidity of cascade reservoirs of Wujiang company is not strong, the outflow flow changes greatly, and Pengshui superior reservoir is Shatuo reservoir with daily regulation. The plan is changeable, and it is difficult to predict the inflow flow of the Pengshui reservoir, which restricts the reservoir operation of the Pengshui Yinpan cascade hydropower station.

At present, the centralized control center of Datang Chongqing Branch has established a relatively sufficient information-sharing mechanism with the upstream, mainly including the following three aspects: 1) access to the automatic water regime measurement and reporting information of the upstream reservoir, the hourly reservoir water level, inflow and outflow of the power station above Goupitan, and the surface rainfall in the reservoir section; 2) For reservoir operation information, Wujiang centralized control center regularly submits the weekly and monthly power generation plans of Shatuo hydropower station to the centralized control center of Datang Chongqing Branch; 3) Daily communication: upstream and downstream centralized control centers have established a water regime sharing QQ group for daily communication. Since 2012, the central China regulatory bureau of the national energy administration has organized a joint optimal dispatching coordination meeting of Wujiang Cascade Hydropower Stations every year, further promoting the information sharing and dispatching coordination mechanism. There is no benefit distribution mechanism between the upstream and downstream of Wujiang River due to the current situation. The basic principle of upstream and downstream coordination and joint dispatching is to make every effort to achieve success without compromising their respective interests.

2.2 Basin hydropower is complementary to other multi-energy sources

In addition to hydropower energy, there are other power sources in the Wujiang River Basin, such as thermal power, wind power, etc. The total installed capacity of cascade reservoirs operated by Wujiang company accounts for 68% of the Wujiang River Basin. Therefore, the operation and management of cascade reservoirs in the Wujiang River Basin are dominated by the Wujiang company. In addition, the company also has multi-energy power generation industries such as thermal power, wind power, and photovoltaic, of which the installed capacity of hydropower and thermal power is the largest and that of other energy is negligible. Wujiang company is the largest hydropower generation enterprise in Guizhou Province, with hydropower installed capacity accounting for about 46% of Guizhou Province and power generation accounting for about 60% of power grid hydropower generation. Wujiang company has five thermal power plants with an installed capacity of 4500 MW, accounting for 17% of the unified dispatching units of the Guizhou power grid.

Wujiang company changes the competitive relationship between water and thermal power into complementary advantages. Water and fire complementary optimal dispatching is divided into annual water and firepower distribution and optimal adjustment of water and firepower in the middle of the year. The hydrothermal complementary optimal dispatching mainly takes the marginal contribution of thermal power as the initial criterion. On the premise that hydropower does not abandon water, water level control assessment and cascade energy storage at the end of the year meet the requirements of the group company, combined with factors such as power coal supply and hydrothermal power maintenance plan, the hydrothermal complementary optimal dispatching scheme for the next year is formed, which can guide the production of hydrothermal power. In case of large deviation between the actual incoming water and the forecast, tight power coal supply or rising power coal price, non-stop and load restriction of thermal power units, intervention by superior units with administrative orders, the principle of minimizing the loss of power generation income and improving the utilization rate of hydropower resources should be changed to optimize the adjustment of water, fire and electricity.

Cascade reservoir management model for Yalong River Basin

1 An overview of cascade reservoirs in a river basin

The Yalong River Basin is a high mountain valley located in a steep area, with a small residential population and a small area of submerged cultivated land. Due to the small number of displaced populations and inundated cultivated land, many social problems are avoided, fewer profit promotion tasks are undertaken, and fewer operation constraints of cascade hydropower stations are imposed. In addition, the Yalong River Valley is deep, the river gradient is large, the location conditions are good, the power generation conditions are superior, and the overall benefits of cascade hydropower stations are high.

The Hydropower Base in the Yalu River Basin is one of the "13 largest hydropower bases in China", with the third-largest reserves of hydropower resources, after the Jinsha River Hydropower Base and the Upper Yangtze River Hydropower Base, which is a treasure trove of China's energy supply. The theoretical reserves of dry water energy in the Yalu River basin reached 22 million kW, the tributary was 11.44 million kW, and the water-energy resources developed in the whole basin were 30 million kW. According to the principle of rational utilization, orderly development, and comprehensive benefits, using the characteristics and advantages of abundant water in the basin, concentrated drop, and small loss of reservoir inundation, the Yalu River mainstream plans to build 21 large and medium-sized rung hydropower stations with good reservoir regulation performance, which can be installed at 30 million kW. When all the rung power stations are completed, the whole basin capacity adjustment coefficient can reach 0.32, will become all rivers in Sichuan Province in the best regulation performance of high-quality hydropower base, in the country is also a handful. The 10 cascades below the two estuaries (the mainstream of Yalong River) operate independently. The electricity of the whole cascade is 46.72 billion KW.h in the dry season (November ~ May of the following year), 65.95 billion KW.h in the flood season (June ~ October), and the ratio of electricity in the dry season to that in the flood season is 1:1.41. The power of the whole cascade is 72.92 billion KW.h in the dry season, 56.03 billion KW.h in the flood season, and the ratio of power in the dry season to power in flood season is 1.3:1. Cascade compensation has excellent benefits, which can effectively realize the optimal allocation and utilization of hydraulic resources.

2 Current situation of management mode

The Yalong River hydropower development management mode is a typical "single owner, single control center". The "single control center" here is the Yalong River centralized control center. With the continuous deepening of cascade rolling development and construction of hydropower stations in Yalong River Basin, to follow the development and management concept of "watershed, collectivization and scintillation", pursue the maximum overall comprehensive benefits of cascade hubs, optimize production and improve the management level, Yalong river company formally established a centralized control center in 2009. On the premise of ensuring the power grid requirements, Optimal control, and regulation of power generation for power stations. At the same time, as the hub of water regime measurement and reporting in Yalong River Basin, the centralized control center is responsible for basin water regime prediction, construction, and maintenance of relevant stations, centralized operation, and management of water regulation etc.

The Yalong River Basin is a vast, sparsely populated, and deep mountain canyon landform, so cascade reservoirs' flood control operation pressure is slight. However, due to the close hydraulic connection between the Yalong River Basin and the middle and lower reaches of the Yangtze River, the cascade reservoirs are also included in the joint flood control operation of the Yangtze River headquarters, which needs to undertake the overall flood control operation task of the Yangtze River Basin and share the flood control pressure for the middle and lower reaches of the Yangtze River. The contradiction between flood control and power generation of reservoir groups in the basin is more prominent in the flood season. In the actual flood control operation process, due to the special geographical and natural environment of Yalong River Basin, the temporal and spatial distribution of rainfall is uneven and extreme, resulting in strong randomness, short flood prediction period, and low prediction accuracy. Due to the fast flood peak process, the time from collecting rain and water conditions, making dispatching plans, and reporting to leaders or superior institutions for decision-making to issuing operation instructions and notifying cascade downstream to make flood control preparations is very urgent. At the same time, the operation process must comply with relevant operation regulations, especially in the flood season. While considering flood control and profit, it will often face the actual flood that can not be fully and accurately predicted. Therefore, the decision-making of cascade reservoir operation is complex, and the responsibility is arduous.

At the same time of flood control, the main task of the Yalong River cascade reservoir operation is to coordinate the contradiction between flood control and profit, reasonably allocate water resources and maximize social and economic benefits. However, there is a lack of unified allocation and management of water resources in cascade reservoirs' actual operation and management. Relevant water administrative departments in the river basin, flood control, and drought relief departments in the Yangtze River Basin, and power grid departments manage according to their

responsibilities. There is competition in water resources distribution among various regions and water departments in the river basin, and it even leads to some ecological environment problems and management conflicts. In addition, the contradiction of reservoir benefit operation is acute, which involves many departments and stakeholders of water resources management, so it is not easy to solve and coordinate.

Cascade reservoir management model for American watersheds

1 Overview of American hydropower development

The United States was one of the first countries in the world to develop hydropower. Hydropower in the United States has been running for more than 130 years, since 1882, when the country's first hydropower station was built. The peak of hydropower development and construction in the United States was from the 1920s to the 1970s. The United States was the world's leading power in hydropower development and utilization and the world's leading power in hydropower development technology during this period. Hydropower was the primary form of electric power in the United States in the first half of the last century. The early industrial and economic development of this country provided opportunities for hydropower development. In 1940, 40 percent of American electricity was generated by hydropower. But since the 1970s, hydropower construction in America has entered an era of steady development. Since the 21st century, the pace of hydropower development has slowed down.

The United States has a smaller share of hydropower, but it is by far the largest renewable, carbon-free energy source in this country. Hydropower has many functions in the power system, such as peaking and valley-filling, frequency modulation, and phase modulation. The pumped storage power station has flexible operation and fast response, which can guarantee the safety and stable operation of the power grid. According to the U.S. Department of Energy Electric Power Annual Report, in 2011, the total installed capacity of the United States was 1.05 billion kW, and the total generating capacity was 4l00.656 billion kW·h. The installed capacity of conventional hydropower was 78.652 million kW, and that of pumped storage power stations was 22.293 million kW. The annual hydropower generation was 319.355 billion kW·h, accounting for 7.8% of the total power generation and 62% of the renewable energy generation. America currently has about 2,500 hydroelectric dams, which can provide 78 GW of traditional hydropower and 22 GW of pumped storage power, and more than 80,000 NPD for water supply and inland river navigation.

2 American water management model

2.1 Overview of watershed water resources management model

In the United States, each state has a great deal of legislative power. The connection between the state government and the federal government is relatively

loose, leading to the implementation of a state-based management system in water resources management. According to the Constitution, the federal government is responsible for formulating the overall policies and regulation of water resources management implemented by the states. The interstate conflicts in water development and utilization are coordinated by the relevant agencies of the federal government. If coordination fails, it is often resolved through legal proceedings.

Water management in the United States involves three levels of agencies: federal, state and local. In the United States, water resources are managed by the Natural Resources Conservation Service of the Ministry of Agriculture, Water Resources Division of the National Geographic Survey, Reclamation Bureau of the Ministry of the Interior, the Army Corps of Engineers under the Department of Defense and National Environmental Protection Agency.

2.2 Characteristics of watershed water resources management model

(1) Tends to take the whole watershed as the management object

The adjustment object of the American Watershed Management Act has undergone a gradual evolution process, which has gradually changed from merely focusing on the river itself to the management of the whole catchment area. From the unique regulation of watershed water resources gradually evolved to the overall consideration of all environmental resources in the watershed. Watershed management is carried out from the overall function of the watershed ecosystem. The relationship between the watershed ecological protection and socio-economic development was emphasized, and the comprehensive management of watershed ecosystem was carried out from the perspectives of economy, environment and social problems. For example, the purpose of the Establishment of the Mississippi River Basin Alliance is to achieve watershed ecosystem management, which requires that the utilization of watershed resources and the protection of resources be considered in watershed planning. It not only improves the economic development and people's living standard in the basin, but also considers the safety of the ecological environment in the basin. This management system is also the key to the success of the Mississippi River basin management.

(2) Collaboration between watershed management agencies and regional departments

A watershed water resources management committee has been set up to deal with the watershed regulation and other matters divided across administrative regions. The typical representatives of the water resources management committee are the Tennessee Valley Authority, the Mississippi River Commission, etc. The water management system combining administrative region management and watershed management has dramatically improved water management efficiency in the United States, which is significant in realizing the sustainable utilization of water resources. The cooperation between the Mississippi River Basin Authority and various departments and regions is a typical example. This cooperation and coordination

model has even become the magic weapon of the Mississippi River basin management success. While specializing in the power system of water environment management, countries also note the role of other administrative departments to adapt centralization to decentralization rather than monopolization of power. But in the process of power crossing, the dominant position of the environmental protection department is established in the power system of all departments.

(3) Diversified and reasonable management methods

Based on strengthening macro-control and overall management of river basins, American Watershed Management Act gradually realizes the marketization of resource management such as the exploitation and utilization of watershed resources to improve the utilization efficiency of resources. Development in the Tennessee Valley, for example, is an optimal combination of highly planned and commercial economic flexibility. The general plan of river basin development passed by Congress is the political law that all states and counties have to follow. The development of specific resources and the operation and management of industrial and mining enterprises are mainly in accordance with economic laws. This authoritative organization, which combines the characteristics of government and enterprises, scientific research institutions and business entities, is very conducive to the implementation and coordinated management of various measures, providing institutional guarantee and prerequisite for rational solutions to flood control, shipping, hydropower development, industry, agriculture, tourism, urban development and other issues.

2.3 The leading management agencies of watershed water resources

There are currently three major water management agencies in the United States, namely, the Bureau of Reclamation, the Army Corps of Engineers, and the Tennessee River Valley Authority, all established to solve a specific problem, according to the federal or congressional authority to manage water. The Army Corps of Engineers operates more than 500 reservoirs across the United States and is the sole agency responsible for constructing and operating large-scale, multi-target reservoir projects across the United States. The Bureau of Reclamation operates about 130 reservoirs in 17 western states, and a large number of its water projects were handed over to local water agencies. The Tennessee River Basin Authority operates 50 reservoirs in seven southeastern states. In addition, the responsibility of each organization in reservoir management depends on the engineering development objectives. The Army Corps of Engineers plays a prominent leading role in building and operating large shipping and flood control reservoirs across the United States; the Bureau of Reclamation is responsible for water resources development and management in the Western United States, with projects expected to focus on irrigation, flood control and water supply; the Tennessee River Valley Authority regulates reservoirs in southeastern states under the authority granted by the Act of Congress of 1933.

Cascade reservoir management model for Canadian watersheds

1 Overview of Canadian hydropower development

Canada has a lot of water resources, with about 9% of the world's freshwater resources. Due to the widespread presence of glaciers, Canada has more than 2 million lakes, with more than 31,000 lakes between 3 and 100km^2 in area and 563 lakes greater than 100km^2.

Canada is the world's second-largest producer of hydropower after China. Some provinces and regions (such as British Columbia, Manitoba, Newfoundland, Labrador, Quebec and Yukon) derive more than 90% of their electricity from hydropower. All the large reservoirs and dams were completed before 1990. Since then, regardless of the scale of hydropower stations, most of them are runoff hydropower stations. Data show that in 2017, Canadian installed hydropower capacity was about 81GW, and its annual hydropower generation was about 403TW·h, second only to China's.

Water resources depend on terrain and climate. Energy development is related to the scale of the electricity market and the availability and price of competitive energy sources such as coal. The development of hydropower and its share of Canada's electricity production varies from province to province, with Quebec, British Columbia and Ontario accounting for the majority of Canadian hydropower generation. Table 1-1 shows the installed hydropower capacity of each province (region) in Canada in 2014.

Tab 1.1 Installed hydropower capacity of Canadian provinces (regions) in 2014

Province/Region	Installed capacity (MW)
British Columbia	14210
Alberta	943
Saskatchewan	868
Manitoba	about 5000 or more
Ontario	about 10000
Quebec	about 40000
New Brunswick	about 950
Nova Scotia	about 376
Prince Edward Island (PEI)	0
Newfoundland and Labrador	6800
Yukon	95
Northwest Territory	56

The most practical hydropower stations are located close to the load centers. Canada has developed hydropower stations in most of these areas. However, there is

still a large amount of untapped hydropower potential, mainly in northern Quebec, Manitoba, British Columbia, Labrador and Yukon, where economic factors affect hydropower development. Therefore, it is essential to reduce construction and financing costs, increase the cost of other competitive energy supplies, and expand electricity markets and transmission channels to develop hydropower in these regions.

2 Canadian reservoir management case-Ottawa River Basin management

2.1 Overview of watershed conditions

The Ottawa River is a tributary of the Saint Lawrence River and most of its course lies on the border between the two provinces. The river has a total length of more than 1130km and a drainage area of 146300km^2, stretching across Quebec and Ontario, 65% of which is located in Quebec and 35% in Ontario.

In the early 20th century, with the growing demand for downstream shipping and electricity, Canada began to consider building reservoirs to store water from natural rivers. The federal government created the Quinze, Timiskaming and Kipawa reservoirs between 1911 and 1914, when Chaudière was the only hydropower station in this river system. At present, there are 13 large reservoirs in the basin, each of which has a storage capacity of at least 200 million m^3. The total storage capacity of these reservoirs is about 12.155 billion m^3, implementing integrated reservoir management following ORRPB (Ottawa River Regulation Planning Board) policies. Figure 3-1 shows the geographical location of major reservoirs in the Ottawa River Basin.

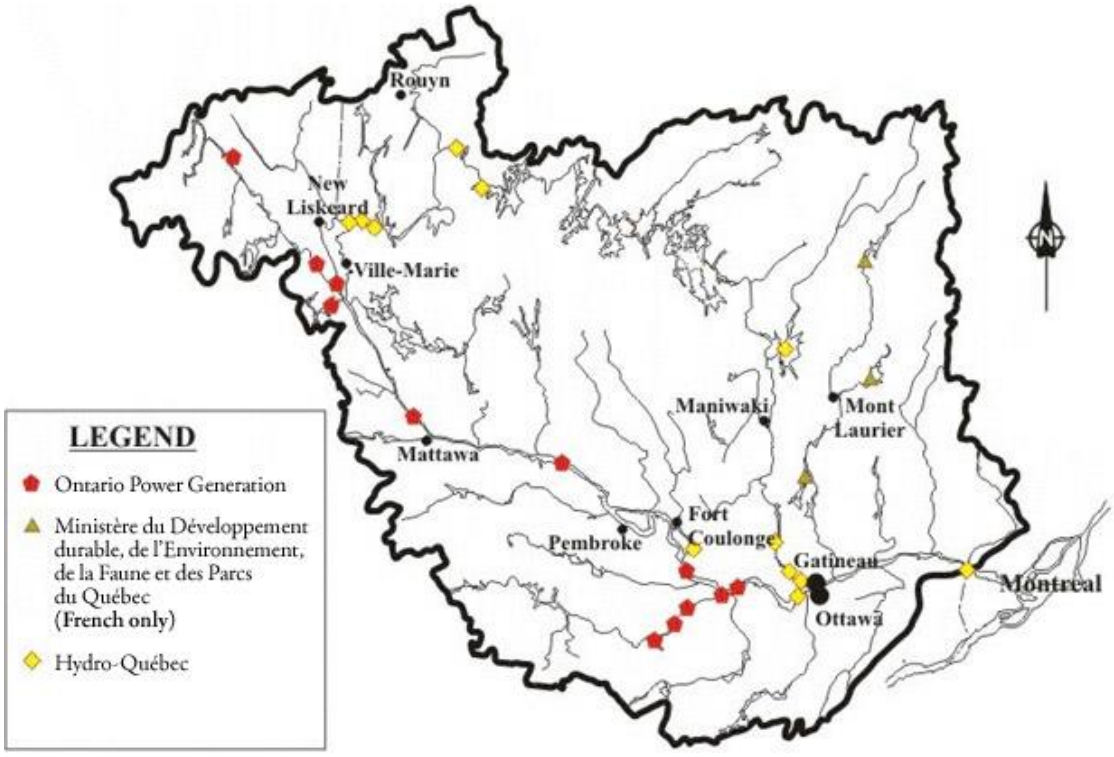

Fig 2.1 Geographical location of major dams in the Ottawa River Basin

In addition to these 13 large reservoirs, there are 14 smaller reservoirs, but they provide less storage capacity overall and are therefore not included in the Ottawa River Basin DSS.

2.2 Watershed management organization

The primary purpose of ORRPB (Ottawa River Regulation Planning Board) and ORRC (Ottawa River Regulating Committee) is to ensure the integrated management of the large reservoirs in the Ottawa River Basin, with the objective of flood control and safeguarding the interests of various users, especially those involved in hydropower production.

ORRPB's role is to develop policies and standards for integrated reservoir management in the agreement. The ORRC is responsible for developing appropriate oversight, operational practices, and procedures to ensure that the reservoirs are operated according to regulations and standards established by ORRPB. As the executive arm of ORRPB, the secretariat's main task is to report and predict hydrological conditions in the Ottawa River Basin through the collection and analysis of data and carry out the functions of ORRPB by developing and running mathematical models.

3 Canadian electricity market

Canadian electricity market reform began in the mid-1990s. The Canadian government first introduced the competition mechanism on the power generation side to adapt to market competition. And then, the government made reforms in areas where electricity is exchanged with the United States, opening up the electricity market and taking advantage of low-cost electricity from abundant water resources to compete in the United States. In the states without such advantages, the state assembly voted on the degree of openness of the electricity market and ultimately decided whether to open the electricity market to competition.

Canadian regulatory agencies are divided into national and provincial levels. National regulatory agencies include the Natural Resources Council (NRC) and the National Energy Board (NEB). NRC is the department in charge of energy management on behalf of the Canadian government. It is mainly responsible for energy development and the research of security policies and related policies, and reports to the Canadian Parliament through the minister of NRC. NEB is primarily responsible for regulating the electricity industry and is directly managed by the minister of NRC, with independent decision-making and regulatory powers. Each province has an energy management and usually an energy commission or public utilities commission, which is responsible for implementing provincial energy policies, reviewing revenue licenses for regulated enterprises, issuing business licenses for electric power enterprises and electricity distribution companies, reviewing or

arbitrating the scale of wholesale markets, and regulating retail markets.

Canadian existing transmission network is divided into two parts: the western area uses 500kV and 138kV connections to connect British Columbia and Alberta; the central and eastern regions joined the power grids of Manitoba, Ontario and Quebec by 115kV and 735kV connections. In addition, six provinces of southern Canada and ten states of the United States have been connected by connections.

In terms of cross-border transactions, Canada has close cross-border electricity trading with the West, Midwest, PJM, New England (ISO-NE) and New York State (NYISO), mainly exporting clean and cheap electricity to the United States. In 2016, Canada exported 73.1 billion kW·h of electricity, 4.3 billion kW·h more than in 2015; the total imported electricity was 9.3 billion kW·h, an increase of 600 million kW·h over 2015. In terms of price, in 2016, the average cost of Canadian electricity exported to the United States was $0.0385 / kW·h, and the average import price of electricity was $0.0263 / kW·h. Net revenue from cross-border transactions in 2016 was approximately $2.7 billion.

Cascade reservoir management model for Norwegian watersheds

1 Overview of Norwegian hydropower development

Since 1965, Norway's economy has grown, and its energy requirements have increased. Technology continues to change, and design and construction constantly have new ideas and new methods. Up to 2000, Norway's total installed hydropower capacity has reached 26 million kW, and the annual generating capacity has reached more than 115 billion kW·h. Hydropower has accounted for 99.4% of the country's total power capacity, constantly meeting the requirements of industry and commerce and the high living standards of social residents, and can also be connected with the Nordic four countries to export power to neighboring countries.

2 Watershed cascade reservoir management

In terms of cascade reservoir management and power market, Norway has enacted a series of relevant laws and established relevant organizations and institutions to establish hydropower development and power market on a standardized, scientific and orderly basis. It has the following four characteristics:

(1) Norway has a clear division of responsibilities for water resources management, with government departments, water resources management associations and power generation companies performing their respective roles.

(2) Hydropower development permit system shall be established by law to ensure state ownership and development control of water resources and maximize the utilization of water resources.

(3) Water resources management organizations should be established to manage water resources uniformly by river basin and implement unified planning for the whole river basin.

(4) The successful reform of the electricity market has brought electricity production and supply into free-market competition and significantly reduced the cost of energy production.

2.1 Management mode and current situation

Norway regards water as state property and limits foreign investment. Although domestic private investment is allowed, the BOT system introduced in 1917 has strict terms for private investors. After 30 years of operation, plants must be handed over to the state unconditionally in good condition (since Norway has little sediment wear problems, plants can run for 70 or 80 years). The licensing system also requires

separate permits for dams, power stations, generation, transmission, distribution and sale of electricity. The licensing system is one of the most critical elements of Norwegian hydropower development regulations, ensuring state ownership and development control of water resources to maximize the use of water resources. Another feature of Norway's water management is that no power station can be built without a unified plan for the whole basin.

Norway attaches great importance to the impact of hydropower development on the environment, such as building dams according to the topography. It does not deliberately seek to maximize installed capacity but puts economic, social, environmental and ecological benefits first. They pay special attention to protecting natural ecology. For example, on the rich salmon rivers, they require installing fish locks to allow salmon to spawn upstream and developers to set up ponds for young salmon. The development of some rivers is even banned to protect the environment. Hydropower generates enormous tax revenues for Norway (the country's second-largest source of income after oil). It also boosts other industries and the local economy, making local people rich.

Under Norwegian law, responsibility for Norwegian energy management and development is divided among several agencies. The Ministry of Petroleum and Energy and its subsidiary, the Norwegian Water and Energy Council (NVE), are government departments responsible for managing Norway's water and energy resources. Under the supervision of NVE, there is an original and vital organization, the Water Management Association (WMA). It effectively coordinates all parties concerned with water resources in the basin, resolves the contradictions and conflicts in the daily water resources utilization process, and plays an essential role in optimizing water resources in the Norwegian basin. In different basins, the corresponding regional water management association manages the optimal management of water resources, such as the Association for Water Resources Management of Groma and Lacan River basin, the largest river management body in Norway, which is responsible for the Groma and Lagan River basin. The plants' centralized control and day-to-day management is carried out by the corresponding energy groups, such as the Eidsiva energy group in the Groma and Lagan River basin. Eidsiva's central control center is responsible for the remote monitoring, controlling, and regulating of more than 40 hydropower stations in the basin. Only the regional maintenance center is responsible for regular or irregular inspection, maintenance and operation of the power stations. It improves the management efficiency, meets the safety production demands of power stations, and reduces the operating cost of enterprises.

2.2 Electricity market

2.2.1 Overview

The Storting passed the *Energy Act* (*Energiloven* in Norwegian) at the end of

1990 and came into force on January 1, 1991. *Energy Act* became the main basis for the reform and restructuring of Norway's power industry and was used as a model for other Nordic countries. The state owns 30 percent of Norway's total power generation capacity, municipalities 55 percent and the private sector 15 percent. In the process of electricity system reform in Norway, the National Power Authority is divided into two parts. The National Energy Company owns 30 percent of the country's generating capacity owned by the former National Power Authority. The other is the State Grid Corporation, which owns the transmission network owned by the former State Power Administration, accounting for about 80% of the country's transmission network. The responsibilities of the State Grid Corporation are operation and development of state-owned transmission systems, planning of the Norwegian transmission system, the joint operation of the Norwegian power system, establishment of system operation procedures and organization of the Norwegian electricity market.

In addition to owning 80% of the main network, State Grid Corporation also signs lease contracts with property owners of the remaining 20%. Norway's regulatory policy is to compete in the power generation and consumer markets and separate the network from the state Grid Company, which the government regulates to ensure that the network is open to all market members.

State Grid Corporation has also set up a subsidiary, Power Market Ltd, to carry out tasks related to the operation and trading of the electricity market. In terms of power supply, the distribution company retains responsibility for connecting users but does not have the power supply right. When a new user needs to be connected to the distribution network, the distribution company in the region must complete the connection. However, customers are not necessarily supplied by the distribution company in their area. Customers can choose suitable suppliers from distribution companies in their regions, electricity suppliers in other regions, electricity retailers, and the electricity market. In other words, in the Norwegian electricity market, networking is separated from the supply business.

Norway's electricity market reforms were designed to introduce competition, not privatization. Hence, the industry is still publicly owned, but the large, provincially owned power companies no longer have a local monopoly. The core features of electricity market reforms include the following five aspects. (1) Transmission networks, whether owned by the state or the provinces, must be open to all market participants to achieve free competition at the retail end of electricity. Distributors no longer have exclusive rights to local power supply services and need to compete with new distributors on price. (2) Electricity consumers can participate in the electricity spot market transactions. The electricity market reform transformed the electricity trading pool, which was previously only open to power producers for occasional electricity trading, into a series of markets, including spot and futures markets open to the end-users of electricity consumption. The spot market, in which electricity consumers trade, provides a price reference for bilateral forward transaction contracts. The expected spot market price becomes the reference price for the bilateral forward

agreements because the traders can trade in the spot market simultaneously. (3) A distance-independent transmission cost system was established for transmission. (4) Consumers can trade in the electricity market without restrictions. (5) Power generation business was separated from transmission and distribution services. Public power enterprises with transmission and distribution networks and generating sets must establish separate departments and accounts for power generation, transmission and distribution services.

2.2.2 Trading patterns in the Nordic electricity market

In 1996, the Norwegian electricity trading pool system was expanded to Sweden and then to Finland and Denmark, organized as a new Nordic electricity trading pool, jointly owned by the Norwegian and Swedish grid companies. The Nordic electricity trading pool consists of three markets: the spot market, the regulated market, and the futures market. The first two markets are physical markets for electricity trading, and the futures market is a financial market for avoiding and managing risks.

Cascade reservoir management model for Brazilian watersheds

1 Overview of Brazilian hydropower

Brazil is one of the countries with the most abundant hydropower resources globally, with superior hydropower resources and development conditions. The average annual precipitation is 1,954mm, and the average annual runoff is 6,950 billion m^3, ranking the highest in the world.

Brazilian electric power industry has always been dominated by hydropower. Hydropower plays an important role in Brazil's energy supply as the most mature technology and the most stable supply of renewable clean energy. In terms of installed capacity, Brazil's theoretical installed hydropower capacity is 248 million kW. The development of hydropower resources in Brazil began in the 1960s and reached its peak in the 1970s when it started to expand the area of exploitation. By 2018, Brazil's total installed capacity was about 158 million kW, of which 104 million kW was hydropower, accounting for 64%. Hydropower accounts for about 73.6% of the total power generation, demonstrating the central role of hydropower. As for hydropower installed capacity, the installed capacity of the Parana River accounts for 56%, that of the San Francisco River 13.4%, and that of the Amazon River 30.5%.

2 Representative power stations

Itaipu Dam (Itaipu Binacional), located on the Parana River (the fifth-longest river in the world), is jointly built by Brazil and Paraguay. Its generating units and capacity are split equally between the two countries, with the first unit generating in 1983. At present, there are 20 generating units (700,000 kW each) with a total installed capacity of 14 million kW and an annual power generation capacity of 90 billion kW·h. It is the second-largest hydropower station in the world with installed capacity, next only to the Three Gorges hydropower station. For more than 30 years, Itaipu Dam has provided sufficient energy for social development and generated substantial social benefits.

With an installed capacity of 11 million kW, Brazil's Mount Mirage power station is the second-largest hydropower station in Brazil. The power station uses ±800 kV UHVDC, the first UHVDC transmission line in the Americas, and can directly transport hydropower resources in northern Brazil to the load center in the southeast. During the construction process of the Mount Mirage power station, there was great controversy on energy and the environment. The construction company invested 13% of the total project fund, 3.7 billion reais, for environmental protection, infrastructure, immigration and other social projects, which made the Mount Mirage

project recognized by the society and played a significant role in promoting the development of this country.

3 Institutional setup of the power system in Brazil

In the restructuring of the Brazilian electricity system in 2004, new institutions were created, and the roles and responsibilities of some existing institutions were redefined.

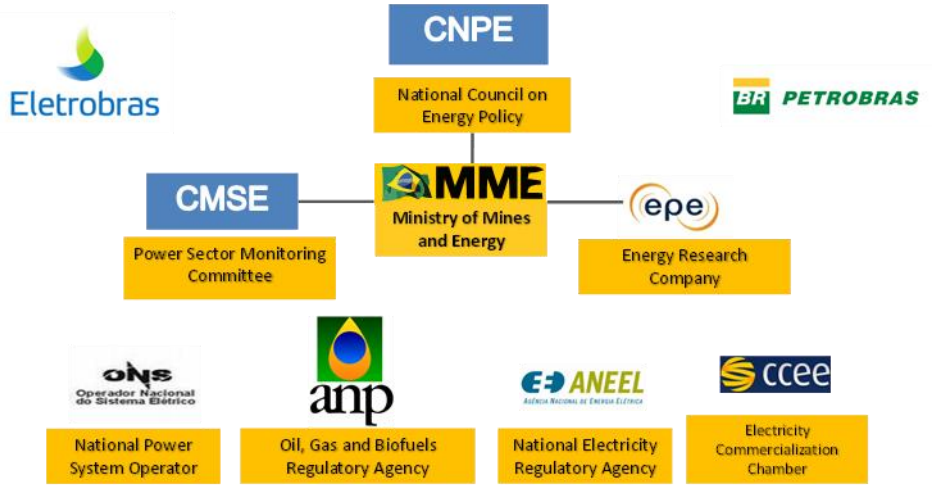

Fig 3.1 Institutional setup in the Brazilian power system

The National Council on Energy Policy (CNPE), an advisory body to the president of the republic, has the following responsibilities: Submit to the president of the republic proposals for a national energy policy integrated with other public policies; recommend that the power sector bid separately for special projects related to MME and propose structural supply assurance criteria.

The responsibilities of the Ministry of Mines and Energy (MME) are as follows: Develop and implement energy sector policies following the guidelines of CNPE; exercise the department's planning function and electricity conferral power; monitor security of supply in the power sector through CMSE and identify preventive measures to restore power supply to prevent joint imbalances between supply and demand, such as demand management and shrinkage of collaborative energy reserves in interconnected systems.

The National Electricity Regulatory Agency (ANEEL) has the following responsibilities: Mediate, control and inspect the operation of the electrical system; the MME delegation holds concession auctions for power generation and transmission projects and bids for energy procurement for Discos (Disturbance Compensation System).

The Oil, Gas and Biofuels Regulatory Agency (ANP) regulates Brazil's oil, gas and biofuel industries. It implements relevant national policies to ensure fuel supply and safeguard consumer interests while ensuring the quality of fuel sold to the end consumer. It also facilitates bidding and contracts for exploration, development and

production activities on behalf of the union.

The National Power System Operator (ONS), under the supervision of ANEEL, is responsible for coordinating and controlling the power generation and transmission facilities of the National Interconnection System (SIN) and planning the operation of the National Independent System. The main objective is to promote the optimal operation of the electrical power system at the lowest cost of the system in compliance with the technical standards and reliability standards set by ANEEL. And to ensure that all agents in the power sector have access to the transmission network in a non-discriminatory manner. The SIN operation is based on the centralized system optimization, scheduling and scheduling schemes, further described in section 3.3.4.

The Electricity Commercialization Chamber (CCEE) has the following responsibilities: Manage the wholesale market through MAE and begin to perform accounting and financial settlement functions in the spot market; calculate the balance settlement price, which is used to evaluate the energy purchase and sale business in the spot market; supervise contract management in contracting market and free contracting market; record power generation and energy consumption data; Conduct electricity purchase and sale auctions at ACR under the authority of ANEEL; Conduct reserve energy auctions under the control of ANEEL and conduct financial settlement of contract value in these auctions.

The main objective of the Energy Research Company (EPE) is to carry out necessary researches so that MME can fully fulfill its role in implementing energy planning. EPE undertakes the following responsibilities: Define the energy mix and indicate the strategy to be followed and the goals to be achieved in the long run; comprehensive energy planning research; the power system (generation and transmission) expansion planning research; promote potential energy studies, including the development of hydrological catchment lists and technical solutions, and the feasibility study on power plant economic and social environment.

The Power Sector Monitoring Committee (CMSE) was established within the MME to permanently monitor and assess the continuity and safety of the national electricity supply. Its responsibilities include: Monitor the development of electricity generation, transmission, distribution, commercialization, import and export activities of electrical energy, natural gas, petroleum and their derivatives; Regularly analyze the security of supply in the electricity, gas and oil markets, taking into account the demand, supply and quality of energy input, hydrological conditions and prospects for the supply of natural gas and other fuels. In addition to MME chairing the meeting, ANEEL, ONS, CCEE, EPE and ANP also attend.

Cascade reservoir management model for the upper reaches of the Yangtze River

1 1 Overview of cascade reservoirs in the upper reaches of the Yangtze River

1.1 Basic situation of the River Basin

The mainstream of the Yangtze River above Yichang city is upstream, which is 4504km long, accounting for 70.4% of the total length of the Yangtze River, and controls a drainage area of 1.1 million km^2. The reach of the Yangtze River above Yibin City is called Jinsha River. It is 3464km long with a drop of about 5100m, accounting for about 95% of the decline of the whole river. It has a significant gradient, many beaches, and rapid water flow. Its main tributary is the Yalong River. The Yangtze River from Yibin to Yichang is 1040km long. The main tributaries are Minjiang River, Jialing River on the north bank, and Wujiang River on the south bank.

1.2 Cascade hydropower development in the basin

The Yangtze River Basin is rich in water resources, with total reserves of 305000 MW, accounting for 39.6%. The upper reaches of the Yangtze River above Yichang account for about 84% of the total hydropower resources of the Yangtze River. It is planned to have five hydropower bases in Jinsha River, Yalong River, Dadu River, Wujiang River, and the upper reaches of the Yangtze River, with an installed capacity of 175.64 million kW, accounting for 59.23% of the total installed capacity of the 13th largest hydropower bases in China.

By the end of 2015, the installed capacity of the five major hydropower bases in the upper reaches of the Yangtze River was 89.6424 million KW, accounting for 50.2% of the technically exploitable capacity. See Table 1 for the development of each hydropower base.

Tab1.1 Development of five hydropower bases in the upper reaches of the Yangtze River（10000 kW、%）

River	Technical exploitation amount	Scale completed in 2015	The scale of constructio	Undeveloped scale	Degree of develo

			n underway in 2015		pment
Jinsha River	8140	2996	1260	3884	52.3
Yalong River	2896.34	1440.64	480	1125.7	61.1
Dadu River	2518.86	895.2	1036.8	786.86	68.8
Wujiang	1163.4	1110.9	0	52.5	95.5
Yangtze Rive	3127.5	2521.5	0	606	80.6
Total	**17846.1**	**8964.24**	**2776.8**	**6455.06**	**63.8**

2 Cascade reservoir management in the upper reaches of the Yangtze River

2.1 Administrative privileges

For reservoirs with comprehensive utilization tasks, the participating departments of reservoir management include the power grid dispatching department, shipping department, and environmental protection department. They put forward requirements for reservoir operation in terms of power generation, shipping and ecology. Among them, the power dispatching department is the reservoir management unit's superior power generation dispatching organization. The operation and management of reservoirs in the upper reaches of the Yangtze River are carried out at different levels, such as The State Flood Control and Drought Relief Headquarters (hereinafter referred to as the " State Flood Control Headquarters "), the Yangtze River Flood Control and Drought Relief Headquarters (hereinafter referred to as the " Yangtze

River Flood Control Headquarters "), Provincial (municipal) Flood Control and Drought Relief Headquarters (hereinafter referred to as the " Provincial (municipal) Flood Control Headquarters ") and reservoir management units. Among them, the first three are the administrative units in charge of flood control and are the superior reservoir dispatching organization of the reservoir management unit. The reservoir management units include more than ten development owners, such as China Three Gorges Corporation, Jinsha River Middlestream Hydropower Development Co., Ltd., Guodian Dadu River company, Yalong River Hydropower Development Company, Ltd. and Guizhou Wujiang Hydropower Development Company. For reservoirs with comprehensive utilization tasks, the participating departments of reservoir management include the power grid dispatching department, shipping department, and environmental protection department. They put forward requirements for reservoir operation in terms of power generation, shipping and ecology. Among them, the power dispatching department is the reservoir management unit's superior power generation dispatching organization.

Except that in case of large floods in flood season and large-area drought in special drought years, the Yangtze River Flood Control Headquarters conducts unified regulation of the flood control capacity and emergency water replenishment of the control reservoirs on the mainstream of the Yangtze River. At other times, the Provincial (municipal) Flood Control Headquarters and each reservoir management unit shall dispatch according to the requirements of comprehensive utilization task and power system of the project, mainly aiming at maximizing the power generation benefit of the project.

2.2 Dispatching management

2.2.1 Flood control dispatch

The reservoir groups in the upper reaches of the Yangtze River adhere to the principle that the benefit dispatch is subject to flood control dispatch, and the power generation dispatching (shipping dispatching) is subject to water resources dispatching. Each reservoir has sufficient flood control capacity in the flood season, and the flood control and water regulation are subject to the unified scheduling of the Yangtze River Flood Control Headquarters. For reservoirs that simultaneously undertake the flood control of their rivers and share the flood control tasks of the middle and lower reaches of the Yangtze River, it is necessary to allocate the flood control capacity of the reservoir reasonably. At the same time, coordinate the relationship between the flood control of the river and the flood control of the middle and lower reaches of the Yangtze River. On the premise of meeting the flood control requirements of the river, share the flood control tasks in the middle and lower reaches of the Yangtze River as needed. Under the precondition of meeting the flood control requirements of the rivers where the reservoirs are located, share the flood control tasks in the middle and lower reaches of the Yangtze River according to the needs; The flood control dispatch should take into account the requirements of comprehensive utilization, combine hydrometeorological forecast. On the premise of ensuring flood control safety, make rational use of water resources and correctly deal with the significant relationships between flood control and profit, local and overall, flood season and non-flood season, single reservoir and multi-reservoir. Through the reservoir group joint operation, the purpose of coordination between upstream and downstream of the basin, consideration of trunk and tributary, ensuring flood control safety, water supply safety and ecological safety of the

basin, and giving full play to the comprehensive benefits of reservoir groups can be achieved.

2.2.2 Generation dispatching

The controlled reservoirs in the upper reaches of the Yangtze River have multiple development tasks such as flood control, power generation, irrigation, and shipping. The completed control reservoirs belong to more than ten different development owners, such as the Three Gorges Group Corporation, Datang Group Corporation, Yalong River Hydropower Development Corporation, and Jinsha River Middlestream Hydropower Development Co., Ltd., showing the characteristics of multiple development tasks and multiple owners. Each reservoir management unit shall carry out beneficial purpose regulation on the reservoirs under its jurisdiction. For example, the Three Gorges Corporation is responsible for the power generation dispatching of the Three Gorges, Xiluodu, and Xiangjiaba reservoirs on the mainstream of the Yangtze River. The Yalong River Basin Hydropower Development Corporation is responsible for the power generation dispatching of Jinping first stage and Ertan reservoirs on the Yalong River. The Guizhou Wujiang Hydropower Development Corporation is responsible for the power generation dispatching of Goupitan, Silin, Shatuo, and Pengshui reservoirs on the Wujiang River.

The reservoir management unit exercises dispatching management and coordination in reservoir dispatching, power generation dispatching, reservoir hub operation management, and shipping coordination. At the same time, uniformly accept and implement the dispatching instructions of administrative units with jurisdiction, and participate in the coordination and formulation of relevant professional dispatching schemes. The reservoir operation management unit shall

comprehensively consider the needs of flood control, shipping, water supply, ecology, and other parties according to the incoming water forecast. Prepare the reservoir operation scheme, coordinate the power grid operation organization to implement power generation, optimize the operation of the reservoir, reducing the loss of abandoned water, and give full play to the power generation benefits of the power station.

2.2.3 Ecological operation

Considering the demand of organisms and their habitats, water environment, and sensitive targets for reservoir operation, and clarifying the ecological operation demand parameters of main and branch water reservoirs play an essential role in determining the ecological operation scheme, coordinating the relationship between reservoir operation and ecological environment, maintaining biodiversity and habitat in the Yangtze River Basin, ensuring ecological flow and protecting water quality in critical areas. At present, the research foundation of ecological regulation demand in the Yangtze River Basin is relatively weak. There is only some accumulation in the regulation demand research and practice of natural reproduction of four fish under the Three Gorges dam. The regulation demand for important species protection, important ecological functional areas, and wetland protection is still unclear. It is urgent to carry out relevant regulation demand research and regulation practice

2.2.4 Dispatching coordination

In terms of dispatching coordination, to successfully implement flood control dispatching, drought resistance dispatching and emergency dispatching of reservoir groups, clarify dispatching objectives, dispatching contents, dispatching conditions, implementation subjects, supervision and management of dispatching process, division of

responsibilities and rights of all parties involved, etc. A cross-departmental dispatching coordination mechanism including water conservancy, electric power, transportation, and reservoir management units has been established to coordinate and guide significant problems in the process of unified dispatching.

2.2.5 Information sharing

Since the beginning of 2014, Yangtze River Flood Control Headquarters had organized the construction of reservoir group information sharing platform for joint operation of reservoirs in the upper reaches of the Yangtze River, and prepared and issued *the Management Measures for Information Sharing of Controlled Reservoirs in the Yangtze River Basin (for Trial Implementation)*. At present, the information-sharing platform for reservoirs in the upper reaches of the Yangtze River has been put into trial operation, including 21 large reservoirs in the upper reaches of the Yangtze River, realizing the sharing of basic information on the operation of reservoirs, and playing an essential role in flood control in flood season and water replenishment in the dry season. However, the existing achievements are far from the requirements of realizing comprehensive information sharing and optimizing the resource allocation of cascade reservoirs in the basin. It is necessary to establish a broad, open, and mutually beneficial information-sharing model based on the existing information-sharing mechanism combined with the current development and management of cascade reservoirs in the basin.

The management model of cascade reservoirs in the Yellow River Basin

1 Overview of cascade reservoirs in River Basin

1.1 Basic information of River Basin

The Yellow River originates from the north foot of Bayan Kara mountain in Qinghai Province, flows through 9 provinces (regions) such as Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong, and flows into the Bohai Sea in Kenli County, Shandong Province. The mainstream of the Yellow River has a total length of 5464km, second only to the Yangtze River. It is the second-longest river in China and the fifth-longest river in the world. The drainage area is 752400 km2, with an average annual runoff of 58 billion m3, ranking eighth among the rivers in China.

i

Fig 1.1 Cascade hydropower development in the basin

A total of 49 reservoir hydropower stations are planned to be built in the mainstream of the Yellow River, including 13 above Longyang Gorge, 26 from Longyang gorge to Hekou town, and 10 in the middle reaches of the Yellow River below Hekou town. As of June 2017, 33 reservoirs and hydropower stations have been built in the mainstream of the Yellow River, and 16 projects are to be built.

2 River Basin Cascade Reservoir Management

2.1 Management mode and current situation

The Yellow River Basin has a vast territory and fewer water resources. With the social and economic development, the water consumption of

the Yellow River Basin has increased sharply, showing a "resource-based water shortage" situation as a whole, and the relationship between water supply and demand among provinces is taut. At the same time, topography, geology, climate, and other factors have brought sediment deposition, ice prevention, and other problems to the management of the Yellow River Basin. The Yellow River Basin implements the unified management of water resources in the basin led by the Yellow River Water Conservancy Commission to deal with these problems. The operation of power stations in the basin relies on the overall arrangement of the Yellow River Water Conservancy Commission, which is highly planned.

At present, the construction of Daliushu, Qikou, and Guxian power stations has not yet started. Among the completed reservoirs in the Yellow River Basin, only four power stations with annual (multi-year) regulation performance are Longyangxia, Liujiaxia, Sanmenxia, and Xiaolangdi. Other power stations are daily regulation power stations or runoff power stations, and their operation depends on the operation management of these four power stations. Therefore, the Yellow River Basin has formed a comprehensive utilization engineering system of the whole basin with the four power stations of Longyangxia, Liujiaxia, Sanmenxia, and Xiaolangdi as the main body.

2.2 Comprehensive utilization and sustainable development of River Basin

2.2.1 Administrative management

(1) Yellow River Water Resources Commission of the Ministry of Water Resources

The Yellow River Water Resources Commission of the Ministry of Water Resources is the dispatched office of the Ministry of Water Resources in the Yellow River Basin. It exercises the responsibilities of water administration in the basin on behalf of the Ministry of water resources. It is a central vertical institution with administrative functions. The organization specification is at the Deputy ministerial level. At present, the State implements the system of combining watershed management with regional administrative management in the Yellow River Basin and implements the management mode of combining macro-management (or indirect management) with direct management. Macro management refers to the legal implementation of Basin-wide planning, flood control and flood fighting, water resources distribution, water dispatch, water resources protection, and soil and water conservation by basin institutions through some coordination organizations or mechanisms. Direct management refers to the river basin organization's water activities in the main river reach below Yumenkou, including the construction and management of flood control works and facilities, the management of water, water areas (including estuaries) and water projects, and the management of water intake

permits above the quota in the main river and the designated River reach of important interprovincial (regional) tributaries. The Yellow River Committee shall establish management organizations at all levels directly under it to implement direct management (or unified management) in the above fields

(2) Yellow River Flood Control and Drought Relief Headquarters

Based on the needs of the new situation of flood control and drought relief of the Yellow River in the new period, with the consent of the State Council, the State Flood Control Headquarters approved the Yellow River headquarters to increase drought relief functions and established the Yellow River headquarters for flood control and drought relief in 2007. The responsibilities of the Yellow River Flood Control and Drought Relief Headquarters are:(1) Implement the national guidelines, policies, laws, and regulations on flood control and drought relief. Organize the formulation of relevant rules and regulations for flood control and drought relief in the Yellow River Basin, and supervise their implementation. (2) Organize, coordinate, supervise and guide the flood control and drought relief work in the Yellow River Basin, focusing on strengthening the flood control and drought relief management of significant engineering and nonengineering measures such as the mainstream of the Yellow River and important cross-provincial (regional) tributaries, embankments, flood storage, and detention areas, reservoirs,

etc. (3) Organize the formulation of flood regulation schemes for the Yellow River Basin and flood prevention schemes for important interprovincial (regional) rivers in the basin, examine and approve flood regulation schemes for important interprovincial (regional) rivers in the basin, and coordinate and supervise their implementation. (4) Be responsible for flood control and drought relief operation of important water conservancy and hydropower projects, flood storage and detention areas, ditches, and gates in the Yellow River Basin in accordance with regulations and authorization. (5) Coordinate and solve water disputes involving primary flood control and drought relief work in the mainstream of the Yellow River and cross-provincial (regional) tributaries. (6) Master the significant flood, work, drought, and disaster conditions in the Yellow River Basin, put forward the decision-making, deployment, and dispatching opinions on flood control and drought relief in the Yellow River Basin, and guide, coordinate, and supervise the major flood fighting and rescue, drought relief and disaster reduction in the Yellow River Basin. (7) To undertake other tasks assigned by the national defense headquarters.

2.2.2 Multi-objective scheduling management

(1) Flood control management

The flood control protection of the upper reaches of the Yellow River focuses on Lanzhou, Ningxia, Hetao Plain of Inner Mongolia, Baotou

Lanzhou railway, and industrial and mining enterprises. The flood control in the plain areas along the Yellow River in Lanzhou, Ningxia, and Inner Mongolia depends on dikes and control projects. Liujiaxia reservoir regulates flood in flood season and controls the peak discharge of flood discharge not to exceed 6000 m3/s, equivalent to once in 50 years floods. Longyangxia reservoir focuses on power generation, combined with flood control, irrigation, and water supply. It can also improve the flood control standards of Liujiaxia reservoir, Yanguoxia hydropower Station, Bapanxia hydropower station, and Lanzhou city. During the ice prevention and ice flood in the Ningmeng river section and the lower reaches of the Yellow River, Liujiaxia reservoir, Sanmenxia reservoir, and Xiaolangdi reservoir control the discharge of Ningxia, Inner Mongolia and lower reaches of the Yellow River respectively, and reduce the channel storage increment during the river closure period, to reduce the ice peak during ice melting and thawing. When necessary, the downstream can also use the river widening area and the Yellow River diversion culvert gates on both banks to release the flood and reduce the disaster.

(2) Water dispatching management

With the approval of the State Council, the State Development Planning Commission and the Ministry of Water Resources jointly promulgated and implemented *The Measures for the Management of*

Water Regulation of the Yellow River in December 1998, authorizing the Yellow River Water Resources Commission to carry out unified regulation of the water volume of the Yellow River. *The regulation on Water regulation of the Yellow River*, adopted and promulgated by the executive meeting of the State Council in July 2006, is the primary measure and guarantee to realize the optimal allocation of water resources of the Yellow River, alleviate the contradiction between supply and demand of water resources of the Yellow River and resolve the crisis of cut-off of the Yellow River.

The regulations stipulate that the Yellow River Water Resources Commission shall be responsible for the organization, implementation, supervision, and inspection of water regulation of the Yellow River. The water volume of the Yellow River shall be subject to unified regulation, and the principles of total amount control, section flow control, hierarchical management, and hierarchical responsibility shall be followed. The water regulation of the Yellow River shall first meet the domestic water needs of urban and rural residents, reasonably arrange water for agriculture, industry, and ecological environment, and prevent the interruption of the Yellow River.

(3) Ice prevention dispatching management

After more than 20 years of operation practice, the Yellow River flood control headquarters has experienced repeated processes such as research, application, summary, and re practice in reservoir flood control

operation, accumulated rich operation experience, initially formed a relatively complete flood control operation method for reservoirs in the upper reaches of the Yellow River, reduced the risk of reservoir flood control and minimized the loss of life and property of people along the Yellow River. The measures to maintain the appropriate flow before river closure reduce the flow fluctuation caused by the diversion of water in the section, shape the appropriate river closure flow in line with the actual situation of the river, and reduce the probability of ice jam and ice dam. During the freezing period, the discharge of the reservoir is appropriately reduced, which maintains a certain flow capacity of the frozen river channel and effectively inhibits the rapid growth of the water storage increment of the tank, and reduces the pressure during the river opening period. The moderate reduction of flow regulation during the river opening period effectively reduced the peak flow of ice flood in the river opening period, and the river opening situation changed from " mechanical break-up" to " thermal break-up," which improved the initiative of ice prevention and effectively reduced the ice disaster during the river opening period. In the last decade, based on thoroughly studying the characteristics of river channels under ice flow capacity and flow propagation law, reservoir ice prevention operation has developed in the direction of refinement.

(4) Water and sediment regulation and management

The main tasks of constructing the Yellow River water and sediment regulation system are as follows: scientifically control, utilize and shape floods, coordinate the relationship between water and sediment, and provide an important guarantee for the safety of flood control and ice

cream prevention; the storage capacity of key reservoirs is used to store sediment, especially the coarse sediment which is the most harmful to river siltation; reasonably allocate water resources, ensure the continuous flow of rivers, ensure water for sediment transport and ecology, and ensure the safety of domestic and production water supply.

The management model of cascade reservoirs in the Pearl River Basin

1. Overview of cascade reservoirs in River Basin

1.1 Basic information of River Basin

The Pearl River is the biggest in south China. Originating in Yunnan-Guizhou Plateau, Maxiong Mountain traverses south China from west to east. It is one of the seven major rivers in China, along with the Yangtze, Yellow, Huaihe, Haihe, Songhua, and Liaohe rivers. It consists of Xinjiang, Beijiang, Dongjiang, and the Pearl River Delta. It entered the South China Sea through Humen, Jiao Men, Hung Chi men, Hengmen, Mo Dao Men, Ji Ti Men, Hu Tiao Men, and Yamen, forming Hong Kong, Macao Special Administrative Regions northeast Vietnam.

The Pearl River is rich in runoff and hydraulic resources. There are 570 rivers with a theoretical reserve of 100000 kW and above, with an academic reserve of 46.454 million kW; 2504 hydropower stations can be developed with the technology of single station installed capacity of 5000 kW and above, with a total installed capacity of 39.05 million kW and an annual power generation of 168.2 billion kWh; There are 2263 economically exploitable hydropower stations with a total installed capacity of 37.321 million kW and an annual power generation of 160.6 billion kWh. Among them, the drop of Hongshui River in Xijiang River is concentrated. The flow is large, and the development conditions are superior, known as the "rich mine" of hydraulic resources.

2. River Basin Cascade Reservoir Management

2.1 Current situation of management mode

（1）Overall situation of dispatching management in the Pearl River Basin

The Pearl River Water Resources Commission of the Ministry of Water Resources (hereinafter referred to as the Pearl River Commission), established in 1979, is a watershed management organization

dispatched by the Ministry of Water Resources. The Pearl River Water Resources Commission of the Ministry of water resources (hereinafter referred to as the Pearl River Commission), established in 1979, is a watershed management organization dispatched by the Ministry of water resources. The law exercises water administration responsibilities in the Pearl River Basin, Han River Basin, international rivers east of Lancang River (excluding Lancang River), coastal rivers of Guangdong and Guangxi, and Hainan Province. It is responsible for ensuring the rational development and utilization of water resources in the basin. It is also responsible for managing and supervising water resources in the basin and overall coordination of domestic, production, and ecological water use. Since its establishment, the headquarters of the Pearl River Delta Commission has continuously strengthened the operation and management of river basin reservoirs, gradually standardized the operation and management authority and responsibilities of crucial river basin reservoirs and local boundary reservoirs, continuously expanded the field of river basin operation and strengthened the unified operation and management of river basins. In recent years, the Pearl River Basin's dispatching scheme and plan system has been continuously improved through the dispatching practice. The dispatching management has been gradually standardized, accurate, and rationalized, ensuring flood control safety, water supply safety, and ecological protection of the basin.

(2) Small hydropower management model in the Pearl River Basin

The geographical topography of the Pearl River Basin has created rich and widely distributed small hydropower resources. In remote mountainous areas, the development and utilization according to local conditions have developed the local economy and solved the problem of

local power consumption difficulties. Due to the small investment, low risk, stable benefit, and low operation cost of small hydropower stations, many economic entities such as state-owned, collective, and private enterprises invest in small hydropower construction everywhere to realize the coordinated development of economic, social, and environmental benefits. Its management modes mainly include the following:

1) Single station operation management mode of original power enterprises

The operation and maintenance are separated. Generally, there is operation, electromechanical, hydraulic workshop (Department), and safety supervision department. At the same time, finance, human resources, party, government, workgroup, and other departments are fully equipped due to the small scale of small hydropower and low annual power generation. At the same time, there is a severe problem of " eating from the same big pot. ".

2) Management mode of collective joint-stock power generation company

Affected by state-owned power enterprises, their management applies the original operation and management mode of power enterprises, which is large and comprehensive, and the burden of enterprises is heavy. There are problems "eating from the same big pot, " such as unclear management responsibilities and rights, average income, formalized assessment, setting posts according to people, etc. The enthusiasm of enterprises to improve is not high.

3) Private joint-stock management mode

Its management is entirely different from that of state-owned power enterprises. To maximize interests, its organizational setting is simple, its

personnel allocation is small, and its management mechanism can not meet the needs of average safety production. There are many loopholes in operation management, some basic production management rules and regulations have not been established and improved, and there are hidden severe dangers in production safety.

4) Basin cascade management mode

Cascade hydropower stations in the same river basin shall implement the management mode of cascade centralized control in the river basin, set up corresponding production management departments such as safety supervision, equipment, and operation at the company level, and implement workshop management for the power stations under their jurisdiction. The River Basin company shall allocate the operation and maintenance personnel uniformly, which is relatively fixed.

5) Regional management mode

Small hydropower stations with the same management area, similar geographical advantages, and small scale (10 ~ 50MW) shall implement the regional management mode. The regional companies set up relatively complete production and operation management organizations, equipped with full-time production management personnel such as safety supervision, equipment, and operation, to cooperate and guide the subordinate power stations to carry out production management. The organization setting of subordinate power stations is relatively simplified, the workshop management under the factory director responsibility system is implemented, and only operation and maintenance teams are set to be responsible for the daily operation and maintenance of the power station.

6) Private management mode

Because shareholders privately own its assets, due to lack of

experience in power station construction and operation, unreasonable investment during construction, saving project investment, resulting in poor project quality, etc., which brings hidden dangers to the safe operation of the power station. Imperfect institutions, personnel, and systems, longing for production, focusing on marketing, and lack of management are common problems of private small hydropower stations.

7) Entrusted management mode

Some small hydropower enterprises entrust professional operation and maintenance management companies affiliated with large and medium-sized hydropower stations to conduct power generation operations. The technical force and management ability are guaranteed, which reduces the operation risk of small hydropower stations. However, the management process cannot be controlled, making the owner worry about losing interest in the process. The entrusted management investment also weakens the profit space.

8) Company operation, power plant management mode

Establish a management company and implement the general manager responsibility system. The management authority of the general manager (plant director) on personnel, property, and materials is clarified, and functional departments are set up to supervise, coordinate and guide the implementation of safety production and technology in the power plant. Its advantages are clear responsibility, standardized management, few intermediate links, direct and effective command, etc.; The main shortcomings are less staffing, enormous management scope and span, long business approval process, and low efficiency.

2.2 **Comprehensive utilization of River Basin**

The comprehensive utilization of the Pearl River basin includes flood

control, shipping, power generation, water resource allocation, irrigation, and ecological protection. Except for a few backbone cascade hydropower stations such as Longtan and Datong gorge water control projects, which have flood control and shipping functions, most of the other cascade hydropower stations are mainly power generation.

In terms of power generation, the cascade hydropower stations in the Pearl River Basin are under the dispatching jurisdiction of the South Power Grid of China. The South Power Grid of China Dispatching Control Center (hereinafter referred to as the Southern Power Grid Main Dispatching Center) is directly subordinate to the South Power Grid of China and the highest dispatching and command organization for the operation of South Power Grid of China. The Southern Power Grid Main Dispatching Center is responsible for the organization, command, guidance, and coordination of the operation of the whole network, as well as nine professional management work, such as power grid dispatching, operation mode, hydropower dispatching, relay protection, power communication, dispatching automation, safety supervision, technical economy, and comprehensive management.

In terms of water regulation, it is uniformly regulated by the Pearl River Water Resources Committee. In flood control, flood control and water resources dispatching are managed by local water conservancy (flood control) departments at all levels according to territorial management. In terms of dispatching, it is also similar to power dispatching, and there is a relationship between multi-level management or dispatching. Among them, Tianyi, Longtan, and Yantan are mainly subject to the dispatching of the basin headquarters (the headquarters of the Pearl River Commission) and the supervision of the provincial headquarters. At the same time, other power plants are mainly subject to

the dispatching of the provincial headquarters and the leaders of the city and County flood control departments. In terms of shipping, it is uniformly dispatched by the Pearl River Shipping Administration of the Ministry of Transport. The abundant river and numerous tributaries of the Pearl River have brought superior conditions to shipping.

2.3 River Basin power market

As a regional power trading platform, Guangzhou Power Exchange Center is mainly responsible for implementing the national strategy of "power transmission from west to east", implementing the national mandatory plan and the framework agreement between local governments, carrying out cross-regional and cross-provincial market-oriented transactions, promoting interprovincial surplus and shortage power adjustment and clean energy consumption, and gradually promoting the integration of the southern regional market. Adhere to their responsibilities, seek breakthroughs through innovation, constantly explore new mechanisms, new systems, and new models, and maximize the role of interprovincial surplus and shortage power regulation and clean energy consumption platforms.