THE INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME ON HYDROPOWER

IEA Hydropower

Management Models for Hydropower Cascade Reservoirs

Main Report Summary

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IEA Hydro Annex XIV

CYPC

Summary of Cascade Reservoir Management Mode

Taking the basin as a unit to exploit and manage water resources has become the mainstream management model at present. Countries around the world have established diverse basin water management systems that take into account their own national conditions. It is becoming the top priority for reservoir operators to find an effective way to manage cascade reservoirs and maximize their benefits to human being and our society. The Annex XIV has conducted a series of analysis on the world's major river basins in three aspects, including basic conditions of cascade reservoirs, management mode of cascade reservoirs, and key technologies of cascade operation, and also presented typical case studies.

1. Overview of cascade reservoirs in river basins

Asia and South America are two continents with the largest number of rivers in the world. Brazil in the tropics is characterized with abundant precipitation and the largest number of rivers globally, including 9 rivers with an annual runoff of more than 200 billion m^3. In terms of the river length, the Nile River become the longest river in the world, with a total length of 6650 km and flowing through 10 countries. In terms of the basin area, the Amazon river basin in South America is the largest river in the world, 7.05 million km^2. In terms of water volume, the Amazon River is the largest river in the world, with an annual runoff of 6,938 billion m^3.

The earliest study on water energy utilization can date back to the 1880s. Small-scale hydropower plants were established at the Selmez Sugar Factory in France, the Xiawu Chemical Factory in the United Kingdom, and the Kola Mine in the United States. Yunnan Shilongba Hydropower Station started construction in August 1908 and generated electricity in May, 1912 and became the first hydropower station in mainland China. In 1933, the United States put forward the idea of multi-objective cascade development for the first time in the Tennessee river basin development plan and implemented it. In the following years, the cascade reservoirs developed rapidly. During this period, most developed countries exploited hydropower as the focus of their national energy construction. To date, the world's largest hydropower station with installed capacity is China's Three Gorges Hydropower Station. The power station started construction in 1994. The first unit to generate electricity in 2003 and all units were put into operation in 2012, with a total installed capacity of 22.5 million kW.

The implementation of the unified management of the whole basin for the development, utilization, treatment, and protection of rivers is not only in line with the natural attributes of water resources but also conducive to the efficient allocation and sustainable utilization of water resources and promote the all-round economic and social development of the basin. Due to different national conditions, the focus of hydropower development and management mode is different. Developed countries in Europe and America developed hydropower earlier, and their watershed hydropower management is relatively mature. Affected by the comprehensive factors of geography, climate, politics, and economy, hydropower development and management have different characteristics in different countries. For example, Norway has accumulated rich experience in hydraulic development and operation management. In 1917, it passed legislation to divide the responsibilities and powers of water resources management. Government departments, water resources management associations, and power generation enterprises perform their respective duties and implement unified planning for the whole basin for basin development to ensure the interests of all parties. The hydropower management model of the Tennessee River in the United States is a successful model of comprehensive development of the basin. In 1993, the U.S. Congress passed the Tennessee Valley administration act and established the Tennessee Valley Authority (TVA). According to law, TVA is authorized to carry out unified planning, development, utilization, and management of natural resources in the Tennessee river basin. China's hydropower resources are concentrated in the major rivers and tributaries in the southwest and northwest regions, and are managed according to the hydropower development model of "basin, cascade, rolling and comprehensive.".

The total theoretical reserves of water energy resources in the world are 43.6 trillion kW.H/year, the exploitable technical capacity is 15.8 trillion kW.H/year, and the exploitable economic capacity is about 9.5 trillion kW.H/year. There are significant differences in the distribution and development of hydropower resources in the world. Asia is the richest in hydropower resources, accounting for about 40% of the theoretical reserves of global hydropower resources. Its developed hydropower resources account for about 21.1% of the technically exploitable and 35.2% of the economically exploitable. The development and utilization of water energy resources in Europe and North America are high, with more than 68% economic development. In comparison, the technical development degree of water energy resources in Africa is only 7.7%, and the economic development degree is only 12.3%. In 2018, the global newly installed hydropower capacity was 21.8GW, the global total installed capacity has now reached 1292GW, and the power generation of hydropower projects reached a record 4200TWH in 2018. Compared with 2007, the global hydropower economic development has increased by 5 percentage points, and the growth comes from Asia and Africa.

Hydropower is one of the largest clean and renewable power sources in the world. It will not cause pollution due to the combustion of minerals or fossil fuels. It can also provide benefits such as flood control and shipping. Generally speaking, hydropower is playing a positive and beneficial role in most countries in the world.

2. Management mode of cascade reservoirs in river basins

According to the distribution of cascade hydropower stations in the basin, the cascade reservoir group in the basin can be divided into three types, including single series cascade reservoir group, parallel cascade reservoir group, and hybrid cascade reservoir group.

The administrative management of cascade reservoirs in the basin is generally by the hierarchical management mode of main functions, such as water conservancy, power generation, and shipping. The flood control and water resources dispatching management of cascade reservoirs are generally in charge of provincial or municipal flood control and Drought Relief Headquarters. The power dispatching and safety of power stations are primarily in charge of regional or provincial power grids. The operation management units of cascade reservoirs exercise the functions of dispatching, management and coordination in reservoir dispatching, power generation dispatching, reservoir hub operation management and shipping coordination, uniformly accept and implement the dispatching instructions of administrative units with jurisdiction, and participate in the coordination and formulation of relevant professional dispatching plans.

With the development of the economy and society, the development and utilization of water resources have gradually transformed from the single goal water conservancy project in local areas to the comprehensive utilization of water resources in river basins, forming the large-scale river basins and comprehensive function of reservoirs. It is worth noting that the adverse impact of reservoir operation on ecology and the environment can not be ignored. In the process of regulation and operation, according to the actual situation of each reservoir, the proper ecological base flow (minimum or appropriate ecological water demand) can be discharged. Appropriate regulation methods can be used to control water eutrophication, prevent the outbreak of physical and chemical properties and "water bloom" of water body, and avoid the intrusion of the salt tide in the estuary, to reduce or eliminate the adverse impact on the downstream ecology and water environment of the reservoir. From the perspective of river ecosystem protection, the comprehensive utilization of cascade reservoirs will improve the overall comprehensive utilization benefits of cascade reservoirs in the basin and promote the sustainable development of ecology and the environment. In the comprehensive development and utilization of river basins, it has become a general trend to consider the society, economy, and environment as a whole and strive to pursue the unity of the best benefits of the three. Although the national conditions of different countries are not the same and the natural characteristics of rivers are very different, the comprehensive utilization and sustainable development clearly show the following two common characteristics: 1) the establishment of river basin management institutions, focusing on unified management; 2) taking into account social benefits and ecological environment impact to ensure sustainable development.

With the significant increase in exploiting new energy, the energy structure of most countries or regions is changing from a single energy model to a multi-energy complementary model. Hydropower is the primary energy in European and American developed countries, and the optimization and compensation of other energy sources have become the norm. With the adjustment of power energy structure and the rise of new energy in China, the joint optimal operation of hydropower and other energy sources will gradually become the industry's mainstream. Considering that the hydropower, wind energy, solar energy, and other energy have their own advantages and disadvantages, and there is a strong complementary potential to improve energy efficiency, the optimal joint operation of various energy sources is imminent. Wind power and solar photovoltaic power generation belong to intermittent energy. The optimal joint operation of high-quality hydropower, wind power, and photovoltaic power generation will be conducive to maximizing the proportion of renewable energy power entering the network, reducing abandoned wind (light), facilitating the stable and safe operation of the power grid system, and reducing the consumption proportion of fossil energy at the same time.

3. Key technologies of cascade operation in river basins

The implementation of joint cascade dispatching in river basins relys on some relevant key technologies, such as meteorological forecasting technology, hydrological forecasting technology, critical technologies of joint dispatching, and dispatching decision support systems.

The main meteorological elements that conventional weather forecasts include cloud, sunlight, rain, snow, temperature, and the direction and strength of wind, as well as particular disastrous weather in a region or city in the future. The meteorological observatory accurately forecasts the location and intensity of natural disasters, such as cold waves, typhoons, and rainstorms and directly serves industrial and agricultural production and people's lives. Among various meteorological elements, the precipitation is the most crucial for affecting reservoir operation and efficient utilization of water resources. Therefore, the meteorological forecast serving reservoirs and reservoir groups in the basin mainly focus on the precipitation prediction, such as the total precipitation and temporal and spatial distribution of precipitation in the basin controlled by the reservoir. In recent decades, meteorological forecasts for river basins have continuously developed from qualitative and descriptive forecasts to digital and grid-based forecasts. The spatio-temporal resolution and accuracy of meteorological forecasts have been greatly improved. Accordingly, the precipitation prediction technology of reservoir groups in seamless basin covering from short-term approach to short and medium-term, extension period, month and key period (season) on time scale has gradually formed. At present, the approach prediction method of short-term near quantitative precipitation based on radar observation data and the rapid assimilation mesoscale prediction system is the critical technology of the short-term near quantitative precipitation prediction system. The short and medium-term precipitation prediction mainly applies the lattice quantitative precipitation prediction technology of integrated prediction. The extended period precipitation forecast usually adopts three methods, including directly increasing the integral length of the meteorological forecast model, physical analysis and statistics method, and big data prediction method. Monthly and critical period (quarter) scale prediction methods include empirical statistics, physical statistics, numerical models, and prediction methods combining power and statistics. The precipitation forecast in the basin is highly professional. In combination with water regime forecasts, we must keep up with the development of weather forecasts. Accurate precipitation forecast is conducive to extending the prediction period of flood flow forecast, improving the accuracy of flood peak flow forecast, and then formulating reservoir operation strategy according to water and rain information to realize the efficient utilization of water resources.

According to the known information, the hydrological forecast is a qualitative or quantitative prediction of the hydrological state in a certain period of time in the future. Through combining the basic hydrological laws and hydrological models with practical production problems, hydrological prediction technology constitutes specific prediction methods or schemes to serve the actual production. It is widely used in flood control, drought resistance, water resources development and utilization, national economy, and national defense, with substantial economic benefits and many application units. In reservoir management, hydrological forecasting provides a decision-making basis for river basin flood control and optimal utilization of water resources. The focus is on water volume and water level. Forecast items can be divided into runoff forecast, ice forecast, sand forecast, water quality forecast, and typhoon storm surge forecast. Runoff forecast is mainly concerned on reservoir management, divided into the short-term hydrological forecast and medium and long-term hydrological forecast according to the forecast period. The forecast period of the short-term hydrological forecast is generally several hours to several days, including watershed hydrological model methods such as correlation map method, lumped conceptual hydrological model, and distributed physical hydrological model. Medium and long-term hydrological forecast generally refers to the hydrological forecast in which the forecast period exceeds the maximum concentration time of the basin, such as ten days, monthly and annual runoff forecast, and drought and flood trend forecast which mainly adopts the methods of cause analysis and mathematical statistics.

There is a close hydraulic connection between the upstream and downstream reservoirs of cascade hydropower stations, and the upstream reservoirs play a role in retaining and storing the natural incoming water. Large reservoirs with strong regulation capacity change the inflow of downstream reservoirs and the annual and interannual distribution of river runoff, thus changing the runoff characteristics of the whole basin. The essence of the joint optimal operation problem is to abstract the reservoir operation problem into a constrained mathematical optimal solution problem based on the relevant theories of operations research and reservoir operation to coordinate the interests and needs of water departments in the upstream and downstream of the basin, to maximize the comprehensive benefits of cascade reservoirs. Optimal dispatching generally establishes models to maximize economic benefits or consider the comprehensive benefits of flood control, ecology, and shipping. The solution methods include linear programming method, nonlinear programming method, large-scale system method, dynamic programming method, step-by-step optimization method, particle swarm optimization algorithm, firefly algorithm, bat algorithm, cuckoo search algorithm, and other bionic algorithms. Traditional algorithms are widely used in the current practice of optimal scheduling, such as dynamic programming and various improved planning methods. With the improvement of computer hardware and computing ability, various intelligent algorithms have been widely used, such as genetic algorithms and neural networks. Through years of operation and management, hydropower operation companies worldwide have gained rich practical experience in the medium, long-term, short-term, and in-plant economic and efficient operation. In addition, the comprehensive efficiency of cascade reservoirs in the basin has been achieved through continuous improvement and innovation of key technologies for optimal operation.

Operation decision support system is an integrated application system which is able to realize cascade reservoir group prediction and operation scheme preparation and provide technical support for decision-making and management departments. The dispatching decision support system can accurately, timely, and automatically collect the water regime, rain regime, meteorology, hub operation, and other information required for cascade reservoir dispatching. According to the received dispatching requirements, constraint information such as flood control dispatching of the command department, power dispatching of the power dispatching department, and aviation dispatching of the shipping department, the dispatching decision support system will calculate, analyze and comprehensively process this information. With more and more cascade hydropower stations, the amount of data to be processed has become more massive. It is necessary to use distributed database technology to integrate multiple businesses. For example, the complete life cycle management of data and the effective management of multi-source and multi-professional massive heterogeneous data can realize the intelligent perception system with full source coverage, full process traceability, complete data cleaning, and full information transparency. On this basis, machine learning technology is used to make decision support systems have artificial intelligence behavior. Machine learning technology can make full use of human knowledge, describe scheduling decision-making problems, obtain the process knowledge of the decision-making process, and solve reasoning knowledge to carry out creative thinking, logical reasoning, and judgment. The development of the scheduling decision support system is essentially the GIS/database system and model system, which gradually liberates the dispatch decision-maker and finally realizes the intelligent decision-making process.

4. Summary and outlook

The Annex XIV summarizes the characteristics of the main river basins around the world and presents the methods to manage cascade reservoirs in typical river basins. It focuses on analyzing management models of different types of cascade reservoirs, sustainable development, and optimization and complementation of multiple energy sources. On this basis, to provide better technical support for the management of cascade reservoirs in the basin, the four key technologies of meteorology, hydrology, dispatch, and systems have been analyzed and studied.

In the future, as the number of reservoirs constructed in major river basins are close to the maximum, more attention will be attached to optimizing the management and operation methods of cascade reservoirs and its comprehensive benefits. Therefore, continuous efforts should be made to improve the following five aspects, including information sharing, forecast accuracy, dispatching technology, dispatching system, and dispatching management mode.

Attachment

Cases of Hydropower Development and Management in Various Countries