Proc. IAHS, 379, 125–129, 2018
https://doi.org/10.5194/piahs-379-125-2018

Reservoirs operation and water resources utilization coordination in Hongshuihe basin

Chonghao Li[1], Kaige Chi[2], Bo Pang[2], and Hongbin Tang[1]

[1]China Southern Power Grid Dispatching and Control Center, Guangzhou, 510520, China
[2]College of Water Sciences, Beijing Normal University, Beijing, 100875, China

Correspondence: Chonghao Li (lich@csg.cn)

Received: 28 December 2017 – Accepted: 14 January 2018 – Published: 5 June 2018

Abstract. In the recent decade, the demand for water resources has been increasing with the economic development. The reservoirs of cascade hydropower stations in Hongshuihe basin, which are constructed with a main purpose of power generation, are facing more integrated water resources utilization problem. The conflict between power generation of cascade reservoirs and flood control, shipping, environmental protection and water supply has become increasingly prominent. This paper introduces the general situation and integrated water demand of cascade reservoirs in Hongshuihe basin, and it analyses the impact of various types of integrated water demand on power generation and supply. It establishes mathematic models, constrained by various types of integrated water demand, to guide the operation and water resources utilization management of cascade reservoirs in Hongshuihe basin. Integrated water coordination mechanism of Hongshuihe basin is also introduced. It provides a technical and management guide and demonstration for cascade reservoirs operation and integrated water management at home and abroad.

1 Overview

Hongshuihe basin is located in the upper reach of Xijiang River, the mainstream of the Pearl River system. The basin, with an area of 190 000 km^2, locates in the subtropical area. The climate is mild and the rainfall is abundant. The annual rainfall is 1200 mm in its upstream and reached 1500 to 1600 mm in reaches in Guangxi province. From Tianshengqiao of Nanpanjiang in the upper reach to Datengxia of Qianjiang, the total length is 1050 km and the gap reaches 760 m. The average annual water volume reaches 133 billion m^3 at Datengxia dam site.

Hongshuihe Cascade Hydropower Base is one of the 13 major hydropower bases in China and also an important energy base in South China. It plays an important role in power supply in Guangdong and Guangxi. At present, the constructed cascade hydropower stations in Hongshuihe basin include Lubuge, Tianshengqiao I, Tianshengqiao II, Pingban, Longtan, Yantan, Dahua, Bailongtan, Letan, Qiaogong and Changzhou. Together with Datengxia Hydropower Station which is under construction, the total cascade generating capacity is 13 645 MW, and the average annual electricity generation is about 53.3 billion kWh. The sketch map of cascade hydropower stations in Hongshuihe basin is shown in Fig. 1.

In the recent decade, with the economic development the demand for water resources has been increasing rapidly. The reservoirs of cascade hydropower stations in Hongshuihe basin, which are constructed with a main purpose of power generation, are facing more and more serious integrated water use problems. The conflict between power generation of cascade reservoirs and flood control, shipping, environmental protection and water supply has become increasingly prominent. Power dispatching agencies and water resources management departments are facing new challenges on reservoirs operation. Usually multi-purposes operation method is studied and applied in the practical reservoir operations under the conflicting circumstances (Feng et al., 2014; Yang et al., 2010).

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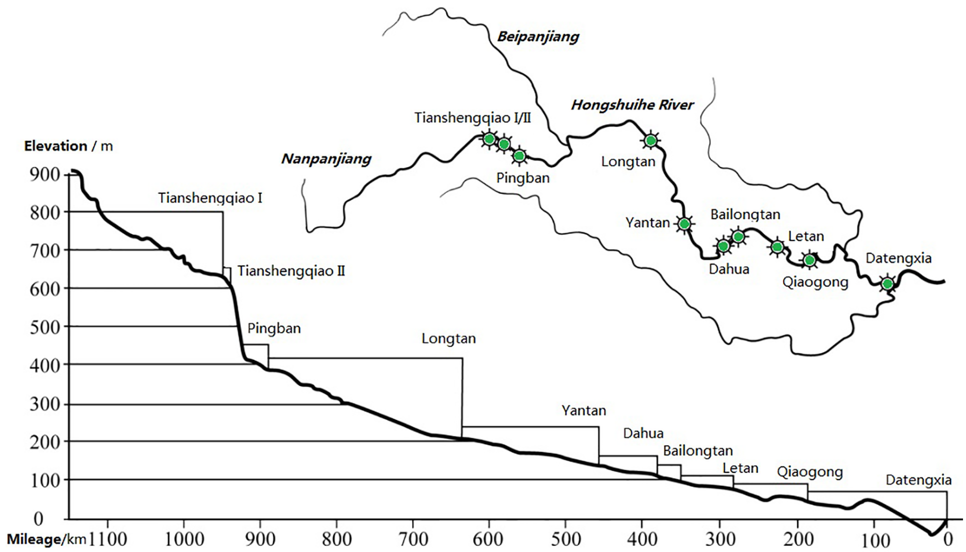

Figure 1. Sketch map of cascade hydropower stations in Hongshuihe basin.

2 Water utilization demands and their impacts on power dispatching

Water use for power generation and other purposes are all utilized through hydraulic engineering facilities such as reservoirs, tunnels and locks. Due to different purposes, conflicts often arise in the way of water use (Zhang, 1983; Feng, 1990). Take flood control for example, the flood control departments require the main reservoirs to reduce water storage and reserve enough flood control capacity to ensure flood control safety in flood season. However, the power dispatching departments need the main reservoirs to increase water storage to ensure the power supply in dry season. There are often contradictions in the way and time of water storing or releasing.

The cascade hydropower stations in Hongshuihe basin, which are constructed with a main purpose of power generation, are an important energy base of south China. Its total installed capacity accounts for about 65 % of the maximum load in Guangxi in 2017, playing an important role in the operation of the Southern Power Grid such as peak load regulation, frequency regulation, voltage control and accident backup in the power supply of Guangdong and Guangxi provinces. The impacts of various types of integrated water demands on power dispatching of cascade hydropower stations is analysed from the perspective of hydropower generation and power supply as below.

2.1 Flood control

The specific requirement of flood control is that water level of reservoir shall not exceed the flood limit water level, or outflow shall not be greater than the specified value. The impact on hydropower generation and power supply include:

1. The reservoir will lose water regulation ability if the flood limit water level is reached or exceeded, and the peak regulation and frequency modulation capacity of the power station will decrease. Water should be discharged to regulate the peak.

2. If water storage is not enough in flood season, the water capacity and power supply will be limited in dry season.

2.2 Shipping

The specific requirement of shipping is that reservoir shall discharge water in the determined flow at a specified time period to ensure the water level of the downstream channel is stable. In case of emergency, it may be necessary to increase or decrease the discharge flow significantly to meet the rescue requirements of ship accidents. The impacts on hydropower generation and power supply include:

1. There is water head loss or even water volume loss in the power station.

2. Power station can only generate power according to the determined output power, losing the capacity of peak regulation, frequency modulation and accident backup.

3. Power stations in upstream and downstream shall cooperate with each other. The cascade power stations will be limited as a whole. The operation mode of thermal power plants and other power plants need to be adjusted and the power supply reliability declined.

4. In case of emergency, a large number of power plants may need to be involved in adjustment, and the grid operation mode will be changed.

2.3 Water supply

The specific requirement of water supply is that reservoir shall discharge water in the determined flow at a specified time period, as required by shipping; or the reservoir water level and the downstream water level should not be less than the specified value in order to meet the water demand of relevant facilities. The impacts on hydropower generation and power supply include:

1. There is water head efficiency loss in the power station. The adjustable output of power stations units will be limited by the extra water supply in dry season.
2. Hydropower station may be forced to drain water during equipment maintenance period in dry season.
3. Power stations in upstream and downstream shall cooperate with each other. The cascade power stations will be limited as a whole. The operation mode of thermal power plants and other power plants needs to be adjusted.
4. Power supply reliability will be declined.

2.4 Environmental or ecological water

The specific requirement of environmental or ecological water is that reservoir shall control the outflow of reservoirs by not less than the specified lower limit so as to maintain the environmental and ecological water in the downstream. In case of emergency, it may be necessary to increase or decrease the discharge flow significantly. The impact on hydropower generation and power supply include:

1. Load peak regulation capacity of power stations and grid will be influenced in dry season.
2. In case of emergency, a large number of power plants may need to be involved in adjustment, the grid operation mode will be changed, and the power supply reliability will be declined.

What's more, power market reform is implementing in the power industry in China at present. The operation of hydropower stations depends not only on water supply, water use and power system operation requirements, but also on the results of the transactions in power market. Unplanned water use, especially water needs in emergency like water pollution accident or shipwreck rescue, may result in market breaches and economic penalties for hydropower owner as a market member. Market trading agencies may have to deal with other power plants temporarily. This may trigger a short-term sharp price increase in the power market.

3 Mathematical models

The contradiction between the integrated utilization of reservoirs and the power generation operation of cascade hydropower stations has become increasingly prominent. In order to guide the operation of cascade reservoirs in Hongshuihe basin and to provide decision support for the daily operation of hydropower stations, this paper presents mathematical models for the integrated utilization of cascade reservoirs. The models use various types of integrated water demand as constraints, including a long-term model and a short-term model according to the different operation periods.

The long-term dispatch model is mainly used for monthly and annual operation plan making of cascade reservoirs in the Hongshuihe basin. The model maximizes the total power generation of cascade, taking the operation requirements of reservoirs, various types of integrated water demand (like outflow and water level control) and power demands of each period of the power system as constraints.

The objective function:

$$E = \mathrm{Max} \sum_{i=1}^{N} \sum_{j=1}^{T} K_i \cdot Q_{i,j} \cdot H_{i,j} \cdot \Delta t \tag{1}$$

Constraints:

$$\begin{cases} \text{Water Level}: & Z_{i,\min} \le Z_{i,j} \le Z_{i,\max} \\ \text{Generating Flow}: & Q_{i,\min} \le Q_{i,j} \le Q_{i,\max} \\ \text{Power Capacity}: & P_{i,\min} \le P_{i,j} \le P_{i,\max} \end{cases} \tag{2}$$

In addition, it should obey the water balance equation:

$$V_{i,j+1} = V_{i,j} + (I_{i,j} Q_{i,j} q_{i,j}) \cdot \Delta t \tag{3}$$

Where E is the total power generation of the cascade reservoirs in the basin; K_i is the output coefficient of the hydropower station i; and $Q_{i,j}$, $H_{i,j}$, $Z_{i,j}$, $P_{i,j}$, $I_{i,j}$, $q_{i,j}$ and $V_{i,j}$ respectively represent for the generating water flow, water head, reservoir water level, power output, inflow, discharge and reservoir water storage of the hydropower station i during time period j.

The short-term dispatch model is mainly used for daily operation schedule of cascade reservoirs in the basin. It aims to minimize the total generating water consumption of the cascade hydropower stations, considering the determined intraday hourly power demand. It takes the operation requirements of reservoirs, various types of integrated water demand (like outflow and water level control) and hourly power grid demand as constraints.

The objective function:

$$W = \mathrm{Min} \sum_{i=1}^{N} \sum_{j=1}^{T} Q_{i,j} \cdot \Delta t \tag{4}$$

The constraints are basically the same with those in the long-term model. While the time period is different.

In addition, the water flow equation among cascade reservoirs, which used to calculate the inflow of reservoir from

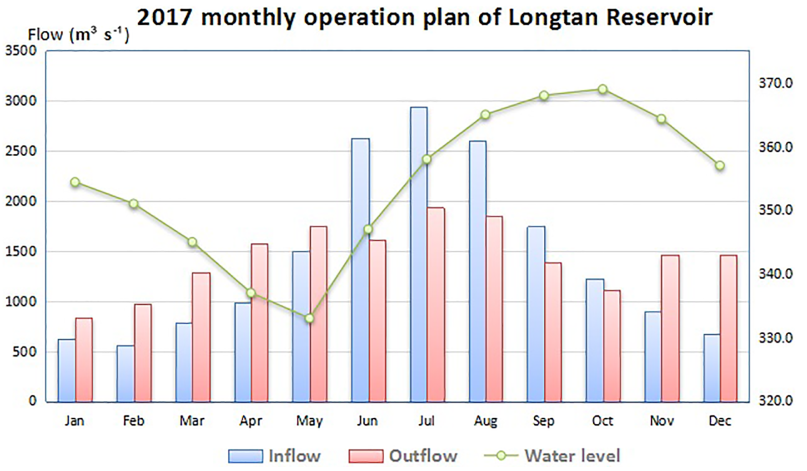

Figure 2. 2017 Monthly operation plan of Longtan reservoir.

its upstream reservoir outflow considering the flow lag time, should be obeyed:

$$I_{i,j} = Q_{i-1,j-dT} + R_{i,j} \quad (5)$$

Where W is the total generating water consumption of the cascade hydropower stations in the basin; $I_{i,j}$, $Q_{i,j}$ and $R_{i,j}$ are the average inflow, quantity of generating water flow and cascade flows between hydropower stations of the hydropower station i during period j respectively; and dT is the water flow lag time from the hydropower station $i-1$ to the hydropower station i.

Reservoirs operation is a typical multi-objective dynamic programming. Usually large system decomposition and coordination methods or dynamic programming algorithms are used in the optimizing solutions (Wang and Zhao, 2003; Shao et al., 1998; Mei et al., 2007; Huang et al., 2014).

Based on the mathematical models above, software of cascade hydropower dispatching system in Hongshuihe basin has been developed using Java and Oracle database. It provides good technical support for reservoirs operation decision-making and daily, monthly or annual plan making of hydropower operation. Figure 2 shows the 2017 long-term optimizing calculation results of Longtan reservoir from the dispatching system.

4 Water utilization coordination management

The dispatch management of basin cascade reservoirs involves many industries and departments like water, power, shipping and environmental protection. In fact, it requires not only reservoir dispatch optimization techniques, but also needs a sound and comprehensive water coordination mechanism to strengthen the dispatch and management of reservoirs in Hongshuihe basin. In order to further improve the integrated utilization of water resources and the overall benefits of the whole basin, a water integrated utilization working group, involving many industries and departments like power dispatching agency, flood control agency, waterway management bureau, environmental protection departments, industrial and agricultural water use organizations and hydropower stations, was established. A constant communication and coordination mechanism has formed to share the basin water information timely and resolve the contradictions in water use promptly, which effectively promote the security and efficiency of integrated water utilization. In addition, measures like the tracing and monitoring of integrated water use in the basin, water utilization benefit assessment afterwards furtherly improve the scientific management of water resources utilization in the basin.

Since 2010, the power supply and water demand of all parties have been well coordinated in a series of major integrated water using events through active coordination and scientific operation, such as basin flood control, water transfer in winter and spring, shipping solution of Changzhou navigation lock in dry season and dispose of water pollution accidents. Good results and significant social benefits have been achieved.

5 Summary

This paper introduces the integrated water demand of the cascade reservoirs in Hongshuihe basin, analysing their impact on power generation and supply, and sets up mathematic models, which are constrained by integrated water demand, for cascade reservoirs integrated operation in Hongshuihe basin. It also introduces the basin integrated water coordination mechanism in use and its active role in improving the water resources utilization efficiency in the basin, providing a technical and management demonstration for cascade reservoirs operation and integrated water management at home and abroad.

Data availability. The data are not publicly accessible as the reservoir operation case in this paper is production and operating relevant activity, and the data is under commercial privacy protection.

Competing interests. The authors declare that they have no conflict of interest.

Special issue statement. This article is part of the special issue "Innovative water resources management – understanding and balancing interactions between humankind and nature". It is a result of the 8th International Water Resources Management Conference of ICWRS, Beijing, China, 13–15 June 2018.

Acknowledgements. This research is supported by National Key Research and Development Program (during the 13th Five-year Plan) under Grant No.2016YFC0401309, Ministry of Science and Technology, PRC.

Edited by: Dingzhi Peng
Reviewed by: two anonymous referees

References

Feng, S.: Multi-objective Decision Theory and Its Application, Human: Huazhong University of Science and Technology Press, 1990.

Feng, Y., Tian, Y., Han, J., and Cui, Y.: Reservoir Ecological Power Optimal Operation and Its Applied Research, China Rural Water and Hydropower, 0, 137–141, 2014.

Huang, C., Wang, Z., Li, S., and Chen, S.: A Multi-reservoir Operation Optimization Model and Application in the Upper Yangtze River Basin I. Principle and Solution of the Model, J. Hydraul. Eng., 45, 1009–1018, 2014.

Mei, Y., Xiong, Y., and Chen, L.: A dynamic programming method for the multi-purpose operation of cascade reservoirs, Journal of Hydroelectric Engineering, 26, 1–4, 2007.

Shao, D., Xia, J., and Sun, Z.: Study on Real Optimal Operation Model for the Reservoir of Water Resources Multi-Objective Integrated Utilization, International Journal Hydroelectric Energy, 16, 7–11, 1998.

Wang, X. and Zhao, R.: Theory of Optimal Reservoir Dispatching with Multi-objective and Its Application, J. Hydraul. Eng., 104–109, 2003.

Yang, F., Zhang, X., and Tan, G.: Elementary Study of Multiobjective Operation Model Considering Ecological Operation, Engineering Journal of Wuhan University, 43, 433–437, 2010.

Zhang, Y.: Hydropower Station Optimal Operation, China Water & Power Press, Beijing, 1983.