Research on the decision support system for optimal operation of large reservoir power generation

Étude d'un système d'aide à la décision pour l'optimisation de la programmation des opérations de production d'électricité dans de grands réservoirs

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Abstract. In order to give full play to the efficiency of power generation and improve the utilization rate of water resources, the optimal operation of reservoir power generation has become one of the hot researches by the experts and scholars. Luntan Key Water-Control Project is taken as an example, which gives consideration to the comprehensive benefits of flood control and power generation. Based on building both the mathematical models of flood pre-release control and the medium-long term power generation, a decision support system with fast online optimization is developed by using SOA architecture and J2EE technology. The results show the system can improve the operation level of the reservoir power generation, reduce effectively the water abandoning rate, realize the scientific optimal operation, provide scientific basis for the management decision, and create more comprehensive benefits.

Résumé. Afin de tirer pleinement parti de l'efficacité de la production d'électricité et améliorer le taux d'utilisation des ressources en eau, le fonctionnement optimal de la production d'électricité par réservoir est devenu l'un des sujets de recherche les plus brûlants pour les experts et les universitaires. Le projet de contrôle de l'eau de Luntan Key pris comme exemple, prend en considération les avantages globaux de la lutte contre les inondations et de la production d'électricité. Basé sur la construction à la fois des modèles mathématiques de contrôle préalable aux inondations et de la

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production d'électricité à moyen et long terme, un système d'aide à la décision avec une optimisation en ligne rapide est développé en utilisant l'architecture SOA et la technologie J2EE. Les résultats montrent que le système peut améliorer le niveau de fonctionnement de la production d'énergie du réservoir, réduire efficacement le taux d'abandon d'eau, réaliser le fonctionnement scientifique optimal, fournir une base scientifique pour la décision de gestion et créer des avantages plus complets.

1 Introduction

Based on the tasks undertaken by the reservoir and the prescribed scheduling principles and on the premise of ensuring the safety of the dam, reservoir operation scheduling stores and releases the natural runoff into the reservoir in a planned way to reduce flood and drought disasters and to meet the needs of the local national economy for water resources to the maximum extent using the storage capacity of the reservoir. Due to the random nature of natural runoff and the diversity of scheduling targets, the operation and scheduling of reservoirs is more complicated. How to use high-tech means to optimize the complex problem of reservoir operation and dispatch and to maximize the comprehensive benefits of reservoir flood control and power generation has received great attention from relevant departments.

In recent years, with the rapid development of water conservancy modernization and informatization, the theory and methods of reservoir optimal dispatching have been gradually improved, and a large number of scholars have conducted extensive and in-depth research on reservoir operation dispatching systems [1-5]. These studies have mainly developed corresponding systems around single-objective reservoir dispatching [6-10]. However, there are few similar system studies for multi-objective large-scale flood control and power generation projects.

Taking the Luntan Water Conservancy Project as the research object, which takes the comprehensive benefits of flood control and power generation into account, the paper discusses the realization of the decision support system for optimal dispatching of large-scale reservoir power generation operation so as to achieve the purpose of giving full play to the comprehensive benefits of reservoir power generation and flood control and provide decision support in various fields such as disaster reduction and engineering construction.

2 Overview of the Research Area

Luntan Reservoir is located in Tianzhushan Township, Qianshan County, Jiangxi Province, about 50km away from the county seat. The dam site is located in the Yangcun Aquatic Waterway, a tributary of the Qianshan River in the Xinjiang River System. The geographical position is 117°38'22" east longitude and 28°3'55" north latitude and the control area of the basin above the dam site is 242 km^2 and Luntan Reservoir is a large type (2) water conservancy project that focuses on flood control and irrigation and takes the comprehensive benefits of power generation and water supply into account. The normal water storage level is 252.0m (Yellow Sea elevation, the same below). The design flood level (P=1%) is 254.72m. The checked flood level (P=0.1%) is 256.45m. The total storage capacity is 179.8 million m^3 and the flood control storage capacity is 20 million m^3. Combined with other relevant flood control measures, the reservoir which was completed at the end of 2014 raised the flood control standards on both banks of the downstream Yangcun River from once in 5 years to once in 20 years and the flood control standards on both banks of Qianshan River from once in 10 years to once in 20 years. The designed irrigation farmland area is 106,200 mu, and the irrigation design guarantee rate is 90%; the installed capacity of the power station is 40MW, the guaranteed output (P=90%) is 6MW, the multi-year average water head is 109.92m, and the multi-year average power generation is 60.59 million kW·h.

3 The principle of operation scheduling

When the reservoir is operating and dispatching, the first thing to consider is the flood-control safety of the upper and lower reaches of the dam site and the dam itself. The second is to meet the requirements of irrigation, and then to dispatch the power generation operation, and meet the production water of downstream industrial and mining enterprises and residents' domestic water along the river. The third is to ensure that the flow downstream of the dam and downstream of each water intake section is not less than the minimum ecological flow to meet the water requirements for maintaining the ecology and environment in the river. The water intake point, which is for irrigation water, production water for downstream industrial and mining enterprises and domestic water for residents along the river, is located downstream of the power generation tail water. Such water consumption is discharged by the power generation water transmission tunnel and can be fully combined with power generation water. The downstream section of the dam is located at the power station. When the upstream of the power generation tail water needs to be released to maintain the water environment in the river section, this part of the water is discharged from the vent hole and cannot be combined with the power generation water.

According to the seasonal change characteristics of floods in the Xinjiang River Basin, the water administrative department has planned April 1 to June 30 as the main flood season, and July 1 to September 30 as the post flood season. During the main flood season from April 1 to June 30, the restricted water level of the reservoir during the flood season is 250.0m, and after July 1, the restricted water level of the reservoir during the flood season is 252.0m. When the flood comes and the water level of Luntan Reservoir exceeds the flood limit water level, the reservoir is dispatched according to the flood control operation mode; otherwise, the reservoir is dispatched according to the beneficial operation mode.

4 The construction of reservoir scheduling model

4.1 Flood pre-discharge scheduling model

There are mainly two situations for the pre-discharge power generation dispatch:
The first situation is

$$W_1 = q_{\max} \times T + V_m - V_0 \tag{1}$$

In formula (1), W_1 is the maximum water inflow without any pre-discharge, and q_{max} is the maximum power generation flow. T is the total duration of the whole flood process, and V_m and V_0 are the storage capacity of the flood limit water level and the current water level respectively. When the total amount of flood water entering the reservoir, namely W is less than W_1, it means that when the flood comes, by discharging the maximum power generation flow during the flood process, the reservoir water level should not exceed its flood limit water level after the flood.

The second situation is,

When W_1 is more than the total amount of flood entering the reservoir W, it means that before the flood comes, we should pre-discharge the power generation to avoid water abandonment in an unreasonable way.

$$t = \frac{W + V_m + V_0 - q_{\max} \times T}{q_{\max} - q_{yu}} \tag{2}$$

In formula (2), t is the pre-discharge time, and q_{yu} is the incoming water flow during the pre-discharge period. Under the circumstance of the forecast being adopted, abandonment of water will occur when the pre-release time t is longer than that of the forecast period.

4.2 Medium and long-term power generation scheduling model

For reservoirs with regulation performance of one year or less than one year, the water level at the end of the year is usually set to be the same or not much different from the water level at the beginning of the year.

To this end, considering the characteristics of the Luntan Reservoir (power station) and the upstream and downstream water constraints, this paper builds a medium and long-term power generation dispatching model of Luntan Hydropower Station and analyse the model by using the dynamic programming algorithm (DP algorithm).

Objective function,

$$E = \max \sum_{t=1}^{T} K Q_t H_t \Delta T \tag{3}$$

In the formula (3), E is the power generation capacity of the hydropower station in a certain period of time; K is the output coefficient of the hydropower plant unit. By comprehensive comparison, K is taken as 8.0; Qt is the average power generation flow rate of the t-the period of time (m3/s); Ht is the average power head of the t-th time period (m); ΔT is the length of the time period (s); T is the number of time periods.

Restrictions,

(1) Reservoir water balance equation

$$V_{t+1} = V_t + (q_t - Q_t - S_t) \cdot \Delta t \tag{4}$$

In the formula (4), Vt+1 and Vt are the storage capacity of the reservoir at the beginning of the t+1 period and the beginning of the t period respectively, in ten thousand m3; qt, Qt are the reservoir inflow and power generation flow in the t period respectively, m3/s; St is the amount of discarded water in the t period.

(2) Reservoir water level (storage capacity) constraints

$$Z_{t.\min} < Z_t < Z_{t.\max} \tag{5}$$

In the formula (5), $Z_{t\cdot min}$ and $Z_{t\cdot max}$ are the lowest and highest water levels (m) of the reservoir allowed in the t period, respectively. Since there is a certain functional relationship between the water level and the storage capacity, the water level constraint can also be converted into a storage capacity constraint, namely:

$$V_{t.\min} < V_t < V_{t.\max} \tag{6}$$

In the formula (6), $V_{t\cdot min}$ and $V_{t.max}$ are the minimum and maximum storage capacity of the reservoir allowed in the t-th period (10^4 m^3).

(3) Output constraints of hydropower stations

$$N_{t.\min} < N_t < N_{t.\max} \tag{7}$$

In the formula (7), $N_{t.min}$ and $N_{t.max}$ are the minimum and maximum allowable output (kW) of the hydropower station during the t period, respectively.
(4) Discharge flow restriction of reservoir

$$Q_{t.\min} < Q_t < Q_{t.\max} \tag{8}$$

In the formula (8), $Q_{t.min}$ and $Q_{t.max}$ are respectively the required minimum discharge flow rate and the maximum allowable discharge flow rate (m^3/s) downstream of the reservoir during the t period.

(5) Variable non-negative constraints. All variables meet non-negative requirements.

5 System function realization

With respect to the low utilization efficiency of hydropower resources in the existing dispatching method of Luntan Reservoir and the situation of water abandonment, this paper has developed a set of optimized dispatching decision support system, which provides scientific basis and technical support for realizing the scientific dispatching and flood control decision-making of the reservoir.

5.1 Function module

With the dispatching rules of Luntan Reservoir flood control and power generation, the multi-functional dispatching decision support system has been developed based on the construction of medium and long-term power generation dispatching model and flood pre-discharge dispatching model.

As for its multi-function, it can report the homepage, project basic information, real-time water and rain information, flood pre-discharge dispatching, medium and long-term power dispatching and pre-discharge together. In terms of function, it has a friendly interactive interface, powerful calculation functions and comprehensive analysis and decision-making functions. In terms of structure, each functional module not only has individual use value, but also can interact and share information with other functional modules. The main interface design and functional structure are shown in Figure 1 and Figure 2 respectively.

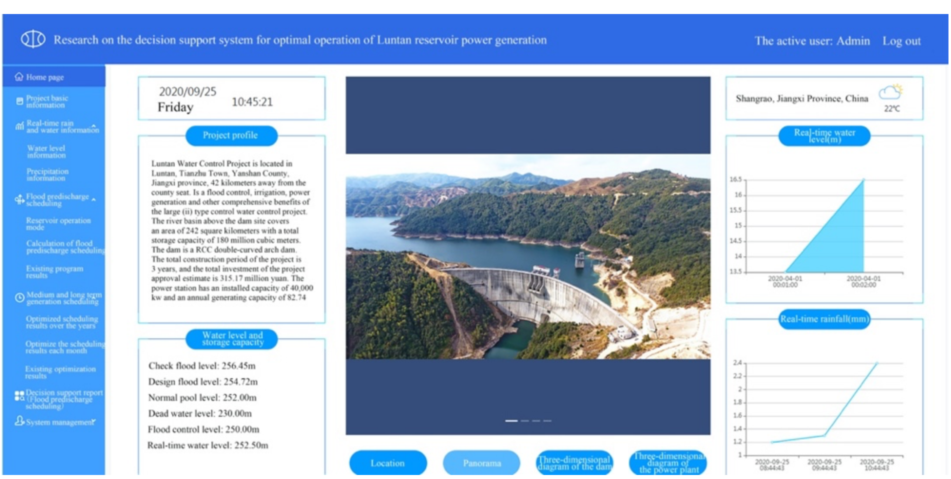

Fig. 1. The main interface of the system.

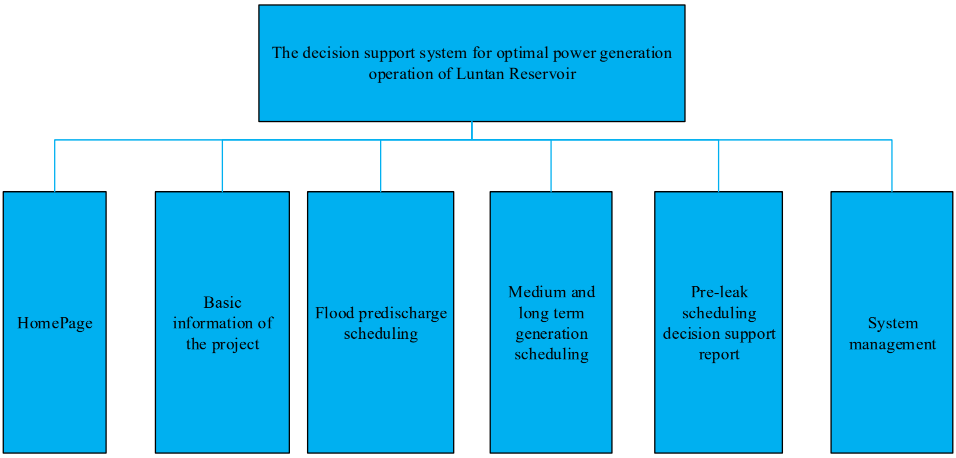

Fig. 2. The functional structure of the system.

(1) Home page

On the basis of the GIS base map, it displays so many functions, such as the project overview, water level storage capacity, real-time water level, real-time rainfall, geographic location, aerial panoramic view of unmanned aircraft, 3D modelling diagram and other functions.

(2) Project basic information

It mainly displays basic geographic information, demarcation and right confirmation information, registration information, safety appraisal information, engineering drawings and engineering features.

(3) Real-time water and rain information

Be access to the information of the established water and rain monitoring system, it can display real-time information such as water level, rainfall, etc. of the reservoir's upstream and downstream. And it also can check historical accumulated rainfall (including hourly, weekly, monthly, and annual accumulated rainfall, displayed as a graph), warning water level, Information such as flood limit water level, current flow, reservoir capacity curve and water level change process.

(4) Flood pre-discharge dispatch

It mainly includes initial condition setting and calculation result as chart displays. The interface is shown in Figure 3.

Fig. 3. Interface of flood pre-discharge dispatch.

1) Initial condition setting.

It provides two types of flood calculations, typical flood process and actual flood process. ① Typical flood process. It can calculate the flood process on 1 or 3 days, and provide input conditions such as the proposal title, the time of the flood coming, the starting water level, the water level at the end of the dispatch, the pre-discharge period, the flood duration, the inflow of the pre- discharge period, and the total flood entering the reservoir. ②The actual flood process. The flood process can be calculated at any time, and the input conditions provided are basically the same as the typical flood process. Only the total amount of flood entering the reservoir changes as the flood entering the reservoir (with an interval of 1 hour).

2) Graphic display of calculation results. The calculation results are displayed in the form of a graph. The abscissa is time, and the ordinate is the amount of water entering the reservoir, the amount of abandoned water, the amount of power generated, and the value of the water level. Each variable is displayed in different colours.

3) Display of calculation result by table. The calculation results are displayed in the form of a table, which mainly includes information such as the title of the calculation plan, the flow of in and out of the reservoir, the amount of water discarded, the amount of power generation, the amount of power generation, the rate of abandonment, the highest water level, the high water level for excess flood control, and the water limit for flooding.

(5) Optimal dispatch of medium and long-term power generation

It mainly includes optimized scheduling results over the years, monthly optimized scheduling calculations and graphical display of calculation results. The interface implementation is shown in Figure 4.

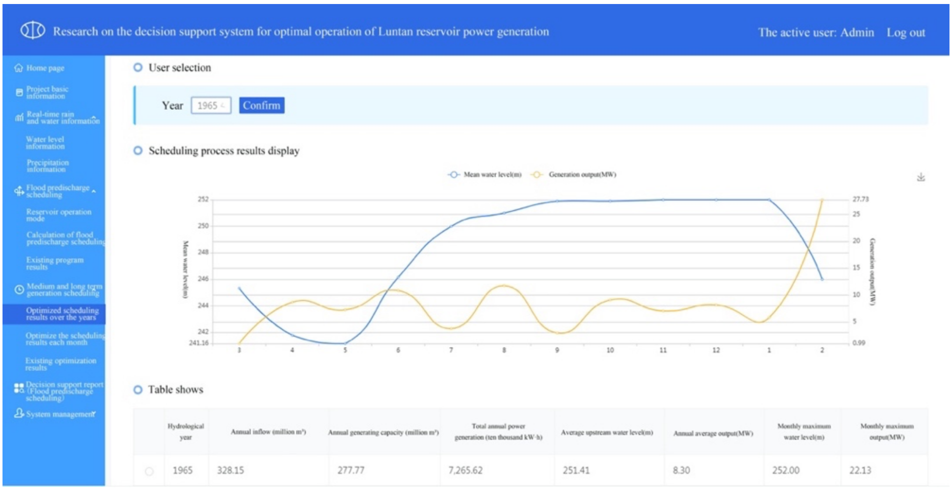

Fig. 4. Interface for mid-to-long-term power generation optimization scheduling.

1) Optimize scheduling results over the years. According to two filtering conditions of year and annual runoff, the supporting system mainly displays the optimized scheduling results of the past 50 years (1964~2013). The display content is mainly the relationship between monthly output and average water level change in a certain year. In the form of a table, it can display lots of data such as the hydrology Year, annual runoff into the reservoir, annual power generation water, annual power generation total, upstream monthly average water level, monthly average output, monthly maximum water level, monthly maximum output, etc.

2) Optimize scheduling calculations every month. By DP algorithm, the system automatically calculates data in the background to obtain the monthly optimization results over the years. According to the results, the optimized dispatch function and correlation coefficients of each month over the years are obtained by fitting (if the correlation coefficient is lower than 0.8, the system will show the user that the function fitting effect is average). Through using the monthly optimization dispatch function, the system can estimate and calculate the average power generation flow of the month and the total monthly power generation based on the storage capacity at the beginning of the month and the average flow of the current month.

3) Graphic display of calculation results. Through the user input the actual monthly power generation value, the system provides a bar chart result display compared with the analysis of the estimated monthly power generation total.

(6) Pre-discharge dispatch decision support report

Mainly aiming at the flood pre-discharge dispatch results of different flood calculations, the system automatically generates pre-discharge dispatch decision support reports to quickly provide users 5 parts content, namely basic project overview, water and rain conditions, flood pre-discharge dispatch results, existing problems and summary. In this way, it can improve user work efficiency, conducive to user decision-making during the flood period.

5.2 Practical application

Using java language programming, this paper realizes calculations of flood pre-discharge dispatch and medium and long-term power generation optimization dispatch model and gets the two calculations packaged into Web services, which provides a unified standardized interface for business applications. The business application layer adopts the J2EE open architecture and uses Web Service to develop an SOA model application system. Taking flood pre-discharge dispatching and medium and long-term power generation optimal dispatching as examples, the paper is focused on the analysis and study of the decision-supporting role of the system in the operation and dispatching of the reservoir project.

(1) Realization of flood pre-discharge dispatch

The actual water abandonment situation of the reservoir during the flood period of 2019 from 18:00 on June 6 to 6:00 on the 11th is selected. Through the online calculation of the system, the results are shown in Table 1.

Table 1. Comparison results in "20190606".

The process	Actual results	Flood pre-discharge dispatch results
Starting water level (m)	246.95	246.95
Final water level (m)	247.46	250
Incoming water volume (10^6m^3)	31.45	31.45
Water discharge (10^6m^3)	28.55	16.34
Power generation water volume (10^6m^3)	17.66	16.34
Amount of discarded water (10^6m^3)	10.89	0
Water abandonment rate (%)	34.63	0
Maximum water level (m)	248.82	250.22
Maximum discharge flow (m^3/s)	152	45
Power generation (10^4 kw·h)	436	403

It can be seen from Table 1 that the actual dispatch rate of the flood on June 6 was 34.63%, and the power generation was 4.36 million kw·h. According to the pre-discharge dispatch calculation, the flood did not need to be pre-discharged in advance. During the process, the maximum power generation flow can be discharged for 100.75h. The water abandonment rate is 0%, and the power generation is 4.03 million kw·h. The reason for the small power generation calculated by the pre-discharge dispatching model is that the reservoir water level was 247.46m after the actual dispatch of the flood on June 6, while the reservoir water level was 250m after the pre-discharge dispatching model was calculated and the amount of abandoned water was reduced by 10.89 million m^3.

(2) Realization of medium and long-term power generation optimal dispatch

Taking the hydrological year as the cycle, this paper calculates and analyses the power generation after optimizing dispatch of the reservoir from March 2017 to February 2018, and from March 2018 to February 2019, and compares it with the actual power generation. The results are shown in Figure 5.

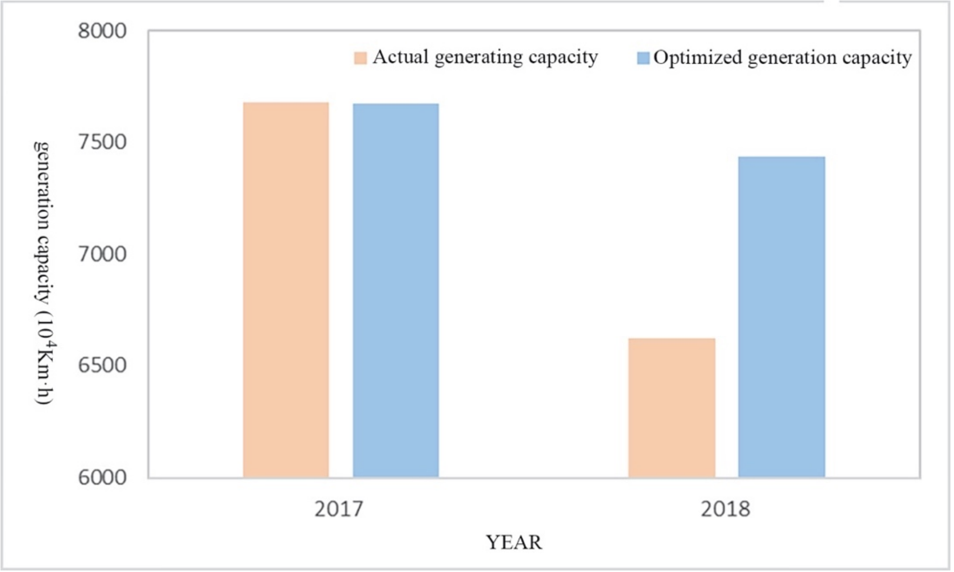

Fig. 5. Comparison of actual power generation and optimized one in both 2017 and 2018.

It can be seen from Figure 5 that from March 2017 to February 2018, the actual power generation of Luntan Hydropower Station was 76.79 million kW·h, and the optimized power generation was 76.71 million kW·h, which has little difference; , the actual power generation of Luntan Hydropower Station was 66.22 million kW·h from March 2018 to February 2019, and the optimized power generation was 74.36 million kW·h, an increase of 12.3%.

6 Conclusion

Taking the Luntan Water Conservancy Project as an example, which takes the comprehensive benefits of flood control and power generation into account and aiming at the problems of inefficient use of hydropower resources and abandonment in the existing scheduling method of Luntan Reservoir, the paper constructs the model flood pre-discharge scheduling and the mid-to-long term power generation dispatch model on the basis of irrigation and downstream ecological water. The results show that during the actual flood on June 6, 2019, the calculation of the pre-discharge dispatch model can greatly reduce the water abandonment rate. Taking March 2018 to February 2019 as the hydrological cycle year, the power generation has increased by 12.3% through the mid-to-long term power generation dispatch model. On this basis, this paper realizes online real-time optimization calculations and visually display the simulation results by using the J2EE open architecture and Web Service, which provides scientific decision-making technical means for making full use of the comprehensive benefits of the reservoir project and realizing the scientific dispatch of the reservoir, has a positive guiding role in promoting the informatization and intelligent management of reservoir projects in Jiangxi province and has a good promotion prospect.

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