A Multiple Dam System Strategy for Zambezi River

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Abstract: In this paper, we removing the Kariba Dam and replacing it with 18 smaller dams along the Zambezi river. Furthermore, we set up three progressive models—the cascade dam system model, the long-term optimal dispatch of the new system model, and the successive linear programming optimal scheduling model, to construct and analysis the new multiple dam system, aiming at keeping a reasonable balance between safety and costs. The whole work is based on a more protective and efficient hydropower system. At last, we provide a strategy for modulating the water flow through the new system dams. Meanwhile, a comprehensive guidance to the ZRA managers against extreme conditions are also offed in our conclusion.

1. Introduction

The Kariba Dam on the Zambezi River is one of the larger dams in Africa which stands 128 meters tall and 579 meters long. The dam forms Lake Kariba which extends for 280 kilometers and holds 185 cubic kilometers of water. However, it was not completed until 1977 due to largely political problems for a total cost of $480,000,000[1].

Its construction was controversial. So far, it has not only supplied a large number of electricity for Zambia and Zimbabwe, but also bring other benefits to nearby countries. On the contrary, it resulted in millions of people being replaced ,the changing of surrounding meteorological conditions and other negative impacts. In addition, as time goes by, floods in the spillway has eroded the bedrock and carved a huge crater, weakening the foundations of the dam,which may cause the collapse of the entire dam. Once that happens, the consequences could be disastrous. Therefore, Zambia River Authority are supposed to take efficient measures to solve this problem. Consequently, A series of good strategies are urgently needed[2,3].

2.Assumptions and Parameters

2.1Assumptions

We make the following assumptions about solving process in this paper. The additional assumptions for each individual model will be detailed along with the introduction and description of that model.

- Assume that the upper and lower dams are located on the same slope;
- Assume that the amount of water flowing into the system from the source will not be affected by the construction of the small dam;
- Suppose the upper and lower reaches of the reservoir are inverted triangular;
- Suppose the effect of building a small reservoir is the same as that of the existing large dam；
- Regardless of the randomness of water space, think at the same time the space of water volume of cascade hydro-power stations is a fixed value.

2.2Parameters

Symbol	Definition
E	the annual power generation of cascade hydro-power stations
t	time
i	the number of hydro-power stations
q_n^t	the mean runoff of hydro-power station *n* during *t* period
S_n^t	the amount of water rejected for the hydro-power station n during t period
Q_n^t	the power generation reference flow of hydro-power station n during t period
V_i^t	the values of the storage capacity of the hydro-power station i to be guaranteed at time t
K	the weighting factor

3. The Models

3.1 Model 1: Cascade Dam System Model

For the potential costs and benefits, we consider the potential costs to include the costs of demolition and the construction costs. We believe that electricity profits and fisheries will be the main benefits based on the hydro-power station base.

According to the elements of hydrological regime, we propose the cascade dam system model. Furthermore, the number and placement of the new dams is initially identified through the same capacity of the new dam system and Kariba Dam as well as the geometrical relationship of each smaller dam .

By observing Google Maps, we found that Kariba Dam is located at the entrance of Kariba Reservoir downstream, if the original dam removed, it will certainly have a significant impact on the reservoir, so according to the title we in the reservoir on the river And the lower reaches of the river to build a number of smaller dams to eliminate the demolition of large dams brought about by the impact.

For the upstream, we first assume that the spacing between the small dams are equal, and then according to the mathematical geometry to obtain the following knowledge:

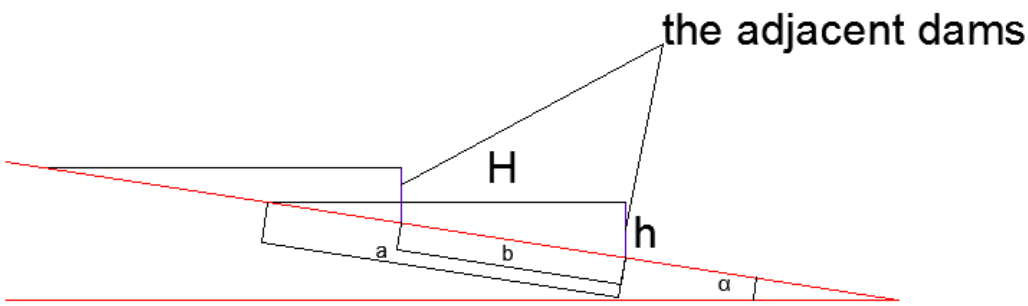

Fig. 1:Front view of geometric relationship between adjacent dams

According to Fig. 1, we are able to get the first model after a series of derivation:

$$V_k = 3b\sin\alpha * h^2 - 3b^2\sin^2\alpha\tan\beta * h + \frac{b^3\sin^3\alpha\tan\beta}{3\tan\alpha} \quad (1)$$

As the upstream and downstream length ratio is approximately 1: 2, we believe that the upstream reservoir capacity should be proportional to the length of the reservoir, that is, about 60 billion cubic meters, while the capacity of the original reservoir is about 180 billion cubic meters. Therefore, a total of 18 small dams are needed to build 12 small dams in the lower reaches of the river, so we should build 6 small dams in the upper stream.

3.2 Model 2: Long-term Optimal Dispatch of The New System

The long-term optimal dispatch of the new system model, in view of the long-term problem, we neglect the time lag of the upstream reservoir flow to the downstream reservoir. Besides, to find an optimal strategy, by the using of known constraints, we get the multiple variables and multiple constraints model about optimal scheduling of cascade hydro-power station.

Based on the proposed scheme of cascade dams in Model 1, we construct the model about long - term optimal dispatch of Cascade Hydro-power Stations. The main function of the dam in this model is protecting surroundings and providing electricity.

It is assumed that the cascade hydro-power station reservoir is connected in series with figure1. The figure is ju

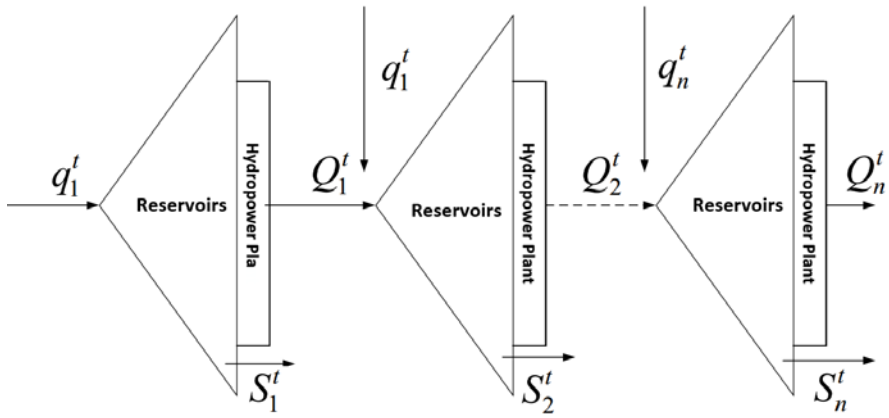

Fig. 2:Cascade hydropower station system structure diagram

According to Fig. 2, we can get a vivid appearance about the new dam system. In addition, we can also acquire constraints. However, the hydraulic connection between cascade dams is complicated. According to our analysis, we adopt a more reasonable and simplified way, that is, when the upstream reservoir storage water, the amount of water from the up stream reservoir minus the amount of storage reservoir plus upstream reservoir and downstream reservoir of the downstream water supply to the downstream power station; when the upstream reservoir water supply, the upstream reservoir from the water supply coupled with the upstream reservoir and downstream reservoirs between the range of water to draw the downstream power station to the water. Therefore, we can get the second model:

$$V_i^t = V_i^{t-1} + \left[q_i^t + K\left(S_{i-1}^{t-1} + Q_{i-1}^{t-1}\right) - S_i^t - Q_i^t\right]\Delta t \tag{2}$$

The model is hard to get the answer in spite of times simplification. The key point of the problem is the discontinuity model.

3.3 Successive Linear Programming Optimal Scheduling Model

SLP is an iterative optimization method that solves nonlinear problems by using linear programming techniques, which has been widely used in practical engineering and has achieved very good results. A large number of mathematical experiments and practical engineering application results show that the algorithm has a fast and good convergence in solving nonlinear problems.

The basic principle of continuous linear programming for solving nonlinear problems is as follows:

1) Use the Taylor series first-order description form to make the nonlinear objective function linearized;

2)The optimal solution of the linearized objective function in the neighborhood is obtained by linear programming and regards it as the new linearized point;

3)The linear programming method is used to find the optimal solution of the linearized objective function in the neighborhood;

4)Repeat the above steps to iterate. When the iteration termination condition is satisfied, the algorithm finds the optimal solution and the optimal objective function value of the problem to be optimized.

The iterative process is an infinitely close approximation to the nonlinear optimal solution. By setting a more appropriate search neighborhood and iterative precision, the optimal solution can be obtained to the maximum extent to reflect the actual situation of the problem to be optimized.

According to the above principles, we can get the finally easier model:

$$E(Q) = \max e\left(Q_1^1, Q_1^2, \cdots, Q_N^T\right) \tag{3}$$

$$\underline{Q_{i,g}^t} \le Q_{i,g}^t \le \overline{Q_{i,g}^t} \tag{4}$$

$$\underline{Q_{i,s}^t} \le Q_{i,s}^t \le \overline{Q_{i,s}^t} \tag{5}$$

$$\underline{Q_{i,V}^t} \le Q_{i,V}^t \le \overline{Q_{i,V}^t} \tag{6}$$

$$\max\left[\max(Q_i^t, Q_{i,g}^t, Q_{i,s}^t, Q_{i,V}^t), Q_{i,k}^t - \Delta S\right] \le Q_i^t \le \min\left[\min(Q_i^t, Q_{i,g}^t, Q_{i,s}^t, Q_{i,V}^t), Q_{i,k}^t\right] \tag{7}$$

Through the meteorological data show: Kariba precipitation conditions every 10 years, the arrival of heavy rainfall will lead to a significant increase in water, an increase of about (0.3-0.5) $*10^8 m^3$, and we calculated by the form of a very poor location data .And the first dam in the dry season: 32.3-29.5 = 2.8 ($*10^8 m^3$); then, when the rainy season is about 50-80 years will produce all the dams facing a dangerous situation in the rainy season: the first five dams: 28.6-26.09 = 2.51($*10^8 m^3$); Dry season, about 56-90 years will be dangerous time length of time, to sum up we think it is very likely that another 50 years after the dam will face all the dangerous situation

4. Conclusions

To sum up, a mathematical model of cascade hydro-power station optimal operation based on continuous linear programming is established. Meanwhile, the dangerous time and situation are indicated by the three model which can give a guidance to the ZRA managers.

The continuous linear programming has good convergence, which can reflect the non-linear factors of the original problem when solving the multi variable nonlinear problems, make up the deficiency of the general linear programming and make the solution of the optimization problem closer to the real situation. At the same time, the optimal solution of the nonlinear problem can be obtained by setting the value of the parameter in the algorithm reasonably, and making the algorithm converge quickly. Therefore, the algorithm of this paper has a unique advantage in solving the optimal operation of cascade hydro-power stations, and it has a good application prospect.

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