Coordinated operation method of cascade hydropower stations considering runoff error

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Abstract. The traditional collaborative scheduling method of cascade hydropower stations group has the problem of imperfect regression model, which leads to excessive water consumption rate. A collaborative scheduling method of cascade hydropower stations group considering runoff error is designed. The influence factors of runoff forecast were obtained, the network parameters were called, and the regression model was built based on the runoff error according to the total power generation of cascade hydropower stations in the degree period. The objective function of hydropower system with hydropower stations as the center was established to optimize the cooperative dispatching mode. Experimental results: The average water consumption rates of the coordinated operation method of cascade hydropower stations group in this paper and the other two kinds of coordinated operation method of cascade hydropower stations group are 34.86%, 57.26% and 59.47% respectively, indicating that the coordinated operation method of cascade hydropower stations group with runoff error is more perfect.

1. Introduction
China has a large number of rivers, abundant runoff and huge drop, which is rich in hydropower resources, ranking first in the world. Since the construction of the first hydropower station, China's hydropower development has gone through a hundred years, and gradually formed the pattern of thirteen hydropower bases. Hydropower is a kind of clean renewable energy, which has the advantages of low power generation cost, strong peak regulation ability, stable operation of units, etc., and has become the first choice of energy development at home and abroad [1-2]. According to the arrangement of hydropower station group, the structure of hydropower station group can be divided into three types: cascade (series) hydropower station group, parallel hydropower station group and series-parallel hybrid hydropower station group. In the joint operation of cascade hydropower stations, the difference in the regulating performance of each reservoir can be used to make the control hydropower stations with better regulating performance change their operation mode to cooperate with the hydropower stations with poor regulating performance, so that the seasonal electric energy can be changed into long-term reliable electric energy, and the total guaranteed output of the system can be improved. Therefore, according to the characteristics of large-scale cascade hydropower stations, more effective and novel optimization theories and methods are needed to provide more scientific theoretical and methodological basis for the operation and management of cascade hydropower stations.
2. Coordinated operation method of cascade hydropower stations considering runoff error

2.1. Obtaining the influencing factors of runoff prediction

According to the layout of the hydropower station group, the structure of the hydropower station group can be divided into three forms: cascade (series) hydropower station group, parallel hydropower station group and series and parallel combination of hybrid hydropower station group [3]. Users can choose different models and set corresponding parameters to forecast runoff according to different basins and different stations. In the known state space, the element distribution mode of hydropower station group in this state space is obtained, and the specific expression formula is as follows:

\[
P = \frac{1}{|L(\delta)\delta \in C|} \quad (1)
\]

In formula (1), \( L \) represents the state space, \( \delta \) represents the element, and \( C \) represents the set of integers. Runoff connection is reflected in the downstream discharge of the upstream hydropower station as a component of the inflow flow of the next hydropower station, and the hydraulic connection is reflected in the utilization of cascade head and the influence of the connected water level of the next hydropower station on the working head of the upper hydropower station [4-5]. The atmospheric circulation and solar activity directly affect the weather conditions of the basin, and play a decisive role in the precipitation and evaporation of the basin, and then affect the formation of runoff, while the underlying surface of the basin directly affects the process of runoff. If any variable of the element in the space satisfies formula (1), the sequence of random variables is said to have no aftereffect. Then the calculation formula for the transfer probability of discrete runoff series in space is as follows:

\[
Q = \frac{G}{\varepsilon - 1} \quad (2)
\]

In formula (2), \( G \) represents part of the observed value, and \( \varepsilon \) represents the state frequency. Cascade hydropower station group compensation regulation is a branch of optimal operation development of hydropower station group, its core is to establish a mathematical model according to the demand, and to find a method to solve the model. In the subsequent runoff forecast of this power station, only each parameter of the network needs to be called and given input, a forecast value can be obtained by using the forecast model. When the runoff data is large enough, the statistical expression formula is as follows:

\[
\eta^2 = 2d \frac{\gamma}{\log_2 d} \quad (3)
\]

In formula (3), \( d \) represents the significance level and \( \gamma \) represents the marginal probability. The underlying surface conditions affect the process of runoff production and confluence in the basin, and the actual runoff and the average actual runoff in the early period can reflect the situation of water retreat in the basin comprehensively, and can show the influence of the underlying surface on runoff formation in the basin.

2.2. Runoff error regression model is constructed

The formation process of runoff is a complex nonlinear dynamic system, which is not only affected by natural factors such as rainfall, temperature and underlying surface, but also by human activities, even atmospheric circulation and astronomical factors [6]. The sources of runoff prediction errors mainly include model structure error, measurement data error and system initial state error, etc. The size of prediction error will directly affect the scheduling mode of hydropower stations [7-8]. By comparing and analyzing the output plan of each cascade power station and the actual output in the power system, it is not difficult to find the important position of peak load balancing. According to scheduling demand, the mean value of runoff data is:
\[ Y = \frac{1}{H} \sum_{i=1}^{e} k_e - 1 \quad (4) \]

In formula (4), \( H \) represents the runoff coverage area, \( k \) represents the real interval, and \( e \) represents the variation range of runoff. In view of the operational flexibility of hydropower stations, the task of peak-shaving is generally given priority, secondary to system stability and flood control requirements. According to the cooperative dispatching object, the model objectives of hydropower station group dispatching can be divided into flood control, power generation, ecology, etc. On the basis of Formula (4), the expression formula of regression model is obtained, which is expressed as follows:

\[ \varphi = \frac{\mu}{\left[ 1(\alpha + 1) \sum_{j=1}^{\beta} j \right]^{\frac{1}{2}}} \quad (5) \]

In formula (5), \( \alpha \) represents the arrangement of runoff data, \( \beta \) represents the real interval, \( \mu \) represents the propulsion scale, and \( i, j \) represents the output coefficient respectively. Such as changes in river morphology and riverbed geomorphology, artificial natural hydrological cycle, biodiversity reduction, etc. In this mode, power generation plan is made based on the known total load task assigned by the power grid. Therefore, the selection of optimization criteria should not only ensure the benefit but also conform to the actual situation, but also reflect short-term benefits and ensure long-term benefits. Therefore, multi-objective optimal operation of cascade hydropower stations based on ecological dispatching has become an important research topic at present, especially for the construction of ecological civilization in China and ensuring the health of river ecosystem. Based on the above, the steps of constructing regression model are completed.

2.3. Optimizing the cooperative scheduling mode

The current scheduling concept of cascade hydropower stations mainly emphasizes the social and economic benefits brought by water resources utilization, but neglects the changes of watershed ecological environment caused by the changes of natural runoff caused by hydropower stations regulation. Power generation is one of the important tasks that large-scale hydropower stations need to undertake. Especially considering the characteristics of load curve, that is, the power station output process should be as consistent as possible with the load process change of system instructions. It can be seen from the above that the model is a multi-objective problem under various constraints. The formula for the minimum deviation sum of the output process of each hydropower station and the expected process of hydropower station group is as follows:

\[ g = \min \left\{ \sum_{i=1}^{l} \left( S_i - \frac{1}{V} \right)^2 \right\} \quad (6) \]

In formula (6), \( S \) represents the actual output in a fixed period, \( V \) represents the actual peak load output of each hydropower station, \( t \) represents the indicated output of the power load curve, and \( g \) represents the sum of residual errors between the actual output process of each cascade power station and the power load curve process. Due to its inherent limitations, the conventional operation of hydropower stations can no longer adapt to the requirements of economic and social development. When the abnormal extra abandoned water exceeds the standard threshold, Formula (6) becomes the following form:

\[ \lambda = \max \left\{ \sum_{i=1}^{l} \left( S \sum_{m \in Z} V - m \right)^2 \right\} \quad (7) \]
In formula (7), $m$ represents the generation flow, $Z$ represents the average generation head, and other variables have the same meanings as formula (6). Swarm optimization scheduling of hydropower stations is in conventional scheduling and optimization of systems engineering theory, developed on the basis of optimization scheduling is based on the theory of system engineering, establish a hydropower station group of target function of the hydropower system as the center, through modern computing technology and optimization method consists of the objective function and constraint condition of system of equations, The optimal scheduling method satisfying the scheduling principle is sought. This part of compensation benefit is the externality generated by the construction and operation of upstream hydropower stations to downstream hydropower stations. It is necessary to quantify the compensation benefits of construction and operation of controlled hydropower stations without considering joint operation:

$$h = \frac{1}{V} \left[ m - n \left( 1 + \sigma^2 \right) \right]$$

In formula (8), $n$ represents outbound flow and $\sigma$ represents inbound and outbound flow. In the model, the incoming water of hydropower stations is described by a deterministic process, which is usually predicted according to the historical runoff data and meteorological information. Because the deterministic model can make good use of all kinds of forecast information, and can integrate the experience of the scheduler, it is convenient and flexible, so the deterministic method is mostly used in the middle and long term optimization scheduling research at present. Based on the above description, the steps of optimizing the cooperative scheduling mode are completed.

3. Case analysis

3.1. Instance background and data
A hydropower station group located in X City was selected as the experimental object, and the average daily runoff of hydropower stations provided by the platform of hydropower station group could be collected. In order to predict runoff on a weekly scale, the average weekly runoff needs to be collected. According to the existing historical operation data of each cascade power station, the clustering indexes of daily load rate, daily peak-valley difference, number of peak value of sunrise force, time of peak appearance of sunrise force and number of sunrise force cycles were calculated, and the scheduling decision library of hydropower stations selected in the experiment was constructed to obtain the calculation results of typical output curves of each power station. Based on sampling survey and historical runoff data of hydropower stations, it is found that the difference between the daily average runoff in one week and the weekly average runoff is negligible. At the same time, the contour coefficient method is used to determine the optimal clustering number of sunrise force feature vector of each power station. The average runoff of each Sunday approximately represents the average runoff of this week. In addition, during data collection, m3 / s was taken as the unit, and it was assumed that the sediment concentration in the water at the time of measurement was not considered. Basic parameters of cascade hydropower stations are shown in Table 1:

| name                  | A      | B      | C      | D      |
|-----------------------|--------|--------|--------|--------|
| Dead water level (m)  | 1206   | 1305   | 1148   | 982    |
| Normal high water level (m) | 1160 | 1223 | 976 | 814 |
| The installed capacity (MW) | 1025 | 960 | 878 | 658 |
| Efficiency coefficient | 9.0 | 8.5 | 9.0 | 8.5 |
| Regulated storage capacity (m³) | 0.36 | 76.2 | 115.1 | 69.7 |
According to Table 1, the basic parameters of the hydropower station group can be obtained, and the cooperative scheduling effect is tested by dynamic programming solution.

3.2. Effect analysis

The cooperative operation method of cascade hydropower stations group based on load distribution and cluster analysis are selected to make experimental comparison with the cooperative operation method of cascade hydropower stations group in this paper. The water consumption rates of three hydropower stations were compared under different runoff conditions. The smaller the value is, the better the performance of the hydropower station is. The experimental results are shown in Figure 1-2:

Fig. 1 Water consumption rate of 1200 (m³/s) runoff (%)

Fig. 2 Water consumption rate of 2600 (m³/s) runoff (%)

According to Fig. 1 and Fig.2, the average water consumption rates of the cooperative operation method of cascade hydropower stations group in this paper and the other two cooperative operation methods are 34.86%, 57.26% and 59.47% respectively. The cooperative operation method of cascade hydropower stations group in the illustration has a lower water consumption rate and is more suitable for practical operation tasks.

4. Conclusion

In view of the problem that the operation characteristics of hydropower stations are not considered in the process of traditional dynamic planning and dispatching of hydropower stations, based on the traditional model, the in plant economic operation of hydropower stations is introduced, the output of hydropower stations in the traditional dynamic planning is improved to the output of optimized
operation in the plant, and the improved dynamic planning model of Hydropower Station Dispatching of hydropower stations is established. The model is applied to the optimal operation of the hydropower station group, and a good operation effect is obtained. In terms of scheduling mode, it adopts the mode of joint decision-making of library group scheduling diagram and load distribution algorithm. Due to the limited research conditions, the precision of collaborative dispatching method of cascade hydropower stations in this paper is not comprehensive enough, and will be strengthened in the future.

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