Optimal Operation Model of Ecological Flow of Hydropower Station Based on Genetic Algorithm and Neural Network

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Abstract. In view of the contradiction between the ecological flow regulation of the reservoir River and the power generation flow regulation of the reservoir with the largest power generation, this paper takes the maximum power generation and the maximum average ecological protection degree as the objective function, and uses the genetic algorithm back propagation neural networks (GA-BP) algorithm to establish the reservoir flow regulation model under the constraints of water balance, reservoir capacity, unit output and unit overflow, The optimal solution of the dispatching scheme is carried out, and the Shulehe hydropower station is taken as an example to verify the optimal scheme. The results show that the optimized dispatching model can ensure the demand of ecological flow, increase 32680 kW·h power generation and 23.85% power generation benefit, so as to provide scientific reference for the rational planning, dispatching and utilization of reservoir water resources.

Keywords: Ecological flow; Optimal scheduling; GA-BP; Neural network.

1. Introduction

River ecological flow is a key indicator to safeguard the ecological function of rivers, and also an important basis for river ecological health evaluation as well as ecological restoration work [1]. The ecological flow is related to the water allocation between upstream and downstream, which may affect the downstream production and living water use as well as have a great impact on the overall ecology of the downstream [2-3], Li Qianxun [4] calculated the ecological flow process of the dam sites of Shuibuya and Diheyan hydropower stations in Qingjiang River based on the month-by-month minimum ecological flow method, RVA method, DC method and month-by-month frequency method, respectively, and used the Tennant method to carry out a result Rationalization analysis. Bai Tao et al. [5] took the Guanting hydropower station as an example, defined the ecological assurance degree of water-reduce reach based on calculating ecological flow under hydrological variation, and established a multi-objective optimal scheduling model of hydropower station power generation and ecological assurance degree, Li Fei [6] took the main stream of the Han River as the research object, analyzed the current situation of the ecological flow guarantee and management of the Han River and its main problems, and put forward the conventional scheduling and emergency scheduling measures for the ecological flow guarantee of the main stream of the Han River, combining with the cascade development of the Hanjiang River Basin with the orientation of the problems and the management needs. How to synthesize the resources and demands inside and outside the river to determine the ecological flow of the river and meet the ecological water demand has become the focus of the ecological flow guarantee research.

Ecological scheduling of hydropower station is a new scheduling model that takes the ecological service function of hydropower station and river into consideration based on traditional hydropower station scheduling, and when constructing the ecological scheduling model, the ecological factors are generally taken as constraints (constraint type) or objective functions (objective type) [7]. Xie Yundong et al. [8] explored the contradictory relationship between hydropower station power generation and ecological benefits based on NSGA-II algorithm, and established a multi-objective optimal scheduling model of hydropower station with the objective of maximizing the annual power generation and the average ecological flow of the hydropower station according to the way of ecological flow discharging in different time scales, and achieved high power generation benefits; Wu Zhuhao [9] investigated the applicability of the R2CROSS method in the ecological flow calculation of small rivers in the south and made optimization suggestions; Peng Hui et al. [10] used a hydropower station group simulation optimization method to establish a hydropower station group multi-objective joint scheduling model considering the ecological water demand of the downstream river, and carried out a comparative analysis of the benefits of multi-objective scheduling of hydropower station group under different ecological water demand flows, and the results showed that the multi-objective scheduling of hydropower station group has become an important way of balancing the competitiveness of each objective.

Most of the current constraints of ecological flow cannot reach the balance between ecological flow and other objectives, this paper takes the Shulehe hydropower station in Jiuquan City, Gansu Province as the research object, and based on the GA-BPNN algorithm, proposes a coupled multi-objective correlation analysis, multi-objective optimization of the ecological flow guarantee method, to provide a new way of thinking and methodology for ecological flow scheduling, management and guarantee.

2. Ecological flow scheduling model parameters

2.1 Objective function

1) Maximum power generation:

$$MaxE = Max\sum_{t=1}^{T} Aq_t H_t \Delta t, \quad t = 1,2,...,T \tag{1}$$

Where E is the total power generation of the hydropower station in the scheduling period, kW·h; A is the output coefficient of the hydropower station; q_t is the power diversion flow rate of the hydropower station in the time period t, m3/s; H_t is the net power generation head of the hydropower station in the time period t, m; T is the total scheduling time period; Δt and is the interval of the calculation time period [11].

2) Largest average level of ecological protection:

$$MaxP = Max\frac{1}{T}\sum_{t=1}^{T} R_t \text{ , t=1,2,...,T} \tag{2}$$

Where P is the multi-year average ecological protection degree corresponding to the ecological flow of the river during the dispatch period; R_t is the ecological flow sequence during the dispatch period [12].

2.2 Constraint condition

1) Water balance constraints:

$$S_{t+1} = S_t + (W_t - U_t)\times \Delta t \tag{3}$$

Where S_t , S_{t+1} is the initial and final reservoir capacity in time period t, W_t is the inlet flow of hydropower station in time period t, m3/s; U_t is the outlet flow of hydropower station in time period t, m3/s; Δt is the interval of calculation time period.

2) Hydropower station capacity constraints:

$$S_{t,\min} \le S_t \le S_{t,\max} \tag{4}$$

Where $S_{t,\min}$, $S_{t,\max}$ is the minimum and maximum permissible reservoir capacity of the hydropower station at time t, respectively, m3.

3) Unit output constraints:

$$N_{t,\min} \le N_t \le N_{t,\max} \tag{5}$$

Where N_t is the output of the hydropower station in the hydropower station in time period t, kW; $N_{t,\min}$, $N_{t,\max}$ is the minimum output value and the maximum output value of the hydropower station allowed in time period t, kW.

4) Unit overflow constraints:

$$q_{t,\min} \leq q_t \leq q_{t,\max} \tag{6}$$

Where q_t is the generation flow rate in time period t, m3/s; $q_{t,\min}$, $q_{t,\max}$ is the minimum and maximum permissible over-engine flow rate at the end of time period t, m3/s [5].

3. Genetic algorithm neural network model and optimization algorithm

The genetic algorithm is an iterative algorithm with global search capability, which takes the biogenetic chromosome as a reference, transcodes the parameters of the solution space of the problem to be solved, and carries out the selection, inheritance, crossover and mutation operations on the transcoded chromosome through iteration [13], and adopts the fitness function to evaluate the chromosome after the selection, inheritance, crossover and mutation operations, and finally screens the optimal chromosome individual [14-15]; and redecodes this optimal chromosome into the actual problem solution space form, and solves it [16]. In this paper, the genetic algorithm is used to optimize the BP neural network, which brings into play the nonlinear mapping ability of the neural network and the global optimization-seeking ability of the genetic algorithm, accelerates the learning speed of the neural network, and integrally improves the whole prediction model and the accuracy and fitting ability [17-18].

In this paper, the GA optimization algorithm is used to build the GA-BP model step by step:

1) Determine the topology of the BP neural network, determine the parameters of the input layer n , the number of nodes in the output layer m , the number of nodes in the hidden layer l and the hidden layer excitation function f . Initialize the connection weights w of the input layer and the hidden layer and the initial value of the hidden layer a. Input the sample data into the input layer, and then calculate the output of the hidden layer H after processing in the hidden layer by Eq. (7).

$$H_j = f(\sum_{i=1}^{n} \omega_{ij} x_i - a_j) \qquad j = 1, 2, ..., l \tag{7}$$

Initialize the hidden and output layer weights ω_{ij} and the output layer threshold b and compute the BP neural network prediction O_k ;

$$O_k = \sum_{j=1}^{n} H_j \omega_{jk} - b_k \qquad k = 1, 2, ..., m \tag{8}$$

2) The initial weights and thresholds of the BP neural network are obtained based on the individuals in the population, and the output is predicted after training the BP neural network with the training set data, and the absolute value of the error between the predicted output of the model and the actual value, E, and the value of the individual fitness, F, are calculated as follows

$$F = k(\sum_{i=1}^{n} abs(y_i - o_i)) \tag{9}$$

where n is the output node of the network; y_i is the desired output of the i th node of the BP neural network; o_i is the predicted output of the i th node, and k is a coefficient.

3) Genetic algorithm selection, crossover and mutation operation, the selection operation method in this paper adopts the roulette selection method, the crossover operation method adopts the real crossover method, the k th chromosome a_k in the j position of crossover operation method is shown in Equation (10); the mutation operation selects the i th individual's j th gene a_{ij} to carry out the mutation, the operation method is shown in Equation (11);

$$\left.\begin{aligned} a_{kj} &= a_{kj}(1-b) + a_{lj}b \\ a_{lj} &= a_{lj}(1-b) + a_{kj}b \end{aligned}\right\} \tag{10}$$

$$a_{ij} = \begin{cases} a_{ij} + (a_{ij} - a_{\max}) * f(g) & r > 0.5 \\ a_{ij} + (a_{\min} - a_{ij}) * f(g) & r \le 0.5 \end{cases} \tag{11}$$

where b is a random number between [0,1]; $a_{\max}$ is the upper limit of the gene a_{ij} , $a_{\min}$ is the lower limit of the gene a_{ij} ; $f(g) = r_2(1 - g/G_{\max})^2$, r_2 is a random number; g is the current iteration number; $G_{\max}$ is the maximum evolutionary number; r is a random number between [0,1].

4) Repeat steps (2)-(3), stop when the termination condition is satisfied, and decode the optimal individual as the initial weights and thresholds of the BP neural network.

4. Case study

This paper takes Shulehe hydropower station as an example, the installed capacity of the hydropower station is 13.5 MW. the maximum net head of the station is 34.42 m, the minimum net head is 30.62 m, and the weighted average net head is 32.23 m. The normal water level is 2100.0 m, the design flood level is 2100.0 m, the calibrated flood level is 2102.2 m, and the dead water level is 2098.0 m. In this paper, we use the GA-BPNN algorithm to Optimized scheduling model, to meet a variety of objective functions and a variety of constraints to adjust the discharge, so that the water resources are more reasonable and efficient use of the adjustment program as shown in Table 1, the discharge comparison chart comparison as shown in Figure 1.

Table 1. Comparison of discharge and ecological flow before and after optimization

Months	Traditional scheduling	Optimal schemes	Ecological flow	Optimal schemes
1	13.60	11.40	2.04	1.14
2	18.30	16.30	2.75	1.63
3	16.10	14.20	2.40	1.42
4	22.60	19.40	3.39	1.94
5	20.80	30.30	3.12	3.03
6	34.20	43.50	5.13	4.35
7	146.00	179.20	21.90	17.92
8	70.70	105.60	10.61	10.56
9	40.10	61.20	6.02	6.12
10	23.10	32.20	3.47	3.22
11	15.90	13.10	2.39	1.31
12	11.90	10.30	1.79	1.03
Total	433.3	536.70	69.33	53.67

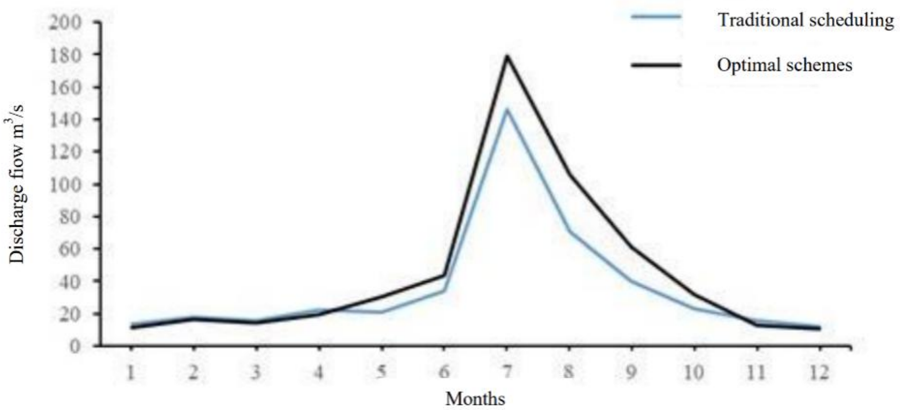

Fig. 1 Comparison of discharge before and after optimization

Comparison of power generation before and after optimization is shown in Table 2, from which it can be obtained that the power generation of the optimized scheduling scheme increases by 32,680 kW·h compared with that of the pre-optimization scheme. The power generation rises by 23.85%, which achieves a reasonable distribution of water resources of the hydropower station under the conditions of meeting the conditions of the maximum power generation, the maximum degree of average ecological protection, and the maximum irrigation benefit, and improves the efficiency of water resources utilization.

Table 2. Comparison of power generation before and after optimization

Months	Traditional schemes kW·h	Optimal schemes kW·h
1	4300	3600
2	5790	5150
3	5090	4490
4	7150	6130
5	6580	9580
6	10810	13750
7	46160	56660
8	22350	33390
9	12680	19350
10	7300	10180
11	5030	4140
12	3760	3260
Total	137000	169680

5. Conclusion

In this paper, based on genetic algorithm optimization back propagation neural network algorithm, we propose a multi-objective optimization with maximum power generation and maximum average ecological protection, and ecological flow guarantee method under multiple constraints of water balance, hydropower station reservoir capacity, unit output and unit overflow. Taking the Shulehe hydropower station as an example, the optimal hydropower station water quantity scheduling scheme was obtained, and the actual application effect of the hydropower station shows that the optimized scheme meets the demand of ecological flow while also significantly improves the power generation efficiency, and the power generation capacity increased by 32,680 kW·h, which is 23.85% higher, and improves the efficiency of comprehensive utilization of water resources.

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