

Research on Short-term Multi-objective Optimization Scheduling oriented Peak Regulation of Power Network

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Abstract. With the succession of river basins and inter-basin hydropower stations, the joint optimal operation of cascade hydropower stations in the river basin has large-scale, nonlinear, strong coupling, and multi-target characteristics, and must consider the effects of hydrometeorology, water demand, and power grid security. Focusing on the preparation of short-term power generation plans for cascade hydropower stations on the Qingjiang River, a comprehensive multi-objective power generation planning model with the largest total power generation and the least load variance on the power grid is established. Based on the constraint processing method of multi-objective optimization scheduling in long-term, the optimal flow distribution technology is adopted to improve the accuracy of power generation planning. The above model is solved by using SMPSO. The results show that the improved algorithm can effectively overcome the shortcomings of slow convergence speed and easy convergence to local optimum. It can improve the power generation efficiency of the whole cascade while responding to the peaking demand of the power grid and provide a new solution to the short-term power generation planning ideas.

1 Introduction

The short-term generation scheduling of cascade hydropower stations is an important part of the cascaded control center, and it belongs to the mode of the largest total power generation and the least load variance. It usually aims at the total generated energy of cascade, the optimal power benefit or the maximum peak shaving revenue. It comprehensively considers short-term runoff forecast, load variation, unit maintenance scheduling, output vibration area and other constraints, so as to effectively utilize and refine the amount of water available for distribution to the day by medium-term dispatch. The traditional power generation planning generally only considers the single target of power generation or generation benefit. When it is necessary to respond to the peak demand of the power grid, it only takes the minimum value of the maximum residual load or the minimum variance as the objective function, and often ignores the overall coordinated relationship between power generation and peak volume that leads to problems such as surplus water, which is not conducive to the effective use of water resources and hydropower resources.

Multi-objective optimization scheduling of reservoirs is usually more complex than single objective optimization, because it needs to consider the coordination relationship between objectives and it is difficult to obtain the optimal solution directly. In general, the solving methods to a multi-objective optimization scheduling problem can be classified into two types: one is to transform multi-objective optimization problem into single objective optimization problem by using method of

weighting^[1,2], constraint method or membership function method^[3,4], which can obtain non-dominated solutions of multi-objective optimization problem by solving single objective optimization problems several times. The other is to apply modern multi-objective intelligentized heuristic algorithms^[5-9], which can get a group of non-dominated solutions meeting conditions through a caculation.

This paper takes the Qingjiang cascade Shuibuya, Geheyuan and Gaobazhou hydropower stations as the research object, and establishes a short-term multi-objective power generation scheduling model for cascade hydropower stations, taking into account the minimum grid residual variance and the largest total cascade power generation. Basing on the method of randomly generating the initial solution and the corresponding repair strategy, a modified multi-objective particle swarm optimization algorithm (SMPSO) that limits the flight speed of the particles to solve the model is applied. The calculation of the actual operating conditions of a certain day is carried out. The results show that the improved algorithm effectively overcomes the problem that the original multi-objective particle swarm optimization algorithm is easy to fall into local optimum, and improves the power generation benefit of the entire cascade while responding to the peaking demand of the power grid; The Pareto optimal solution set with uniform distribution is obtained, which provides data support for the formulation of the cascade power station load distribution scheduling that takes into account the peaking demand, and has certain engineering practical value.

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2 Short-term Multi-Objective Generation Scheduling for Cascade Hydropower Stations on Response of Peaking Regulation

The short-term power generation scheduling of cascade hydropower stations usually takes the daily scheduling period and selects the calculation period of 15min or 1hour. According to the controlling electric quantity or the final water level determined by the medium and long-term, combined with the short-term runoff forecast and load forecast information, comprehensively consider peaking ability, the power and water volume of each power station, etc. Which establish a mathematical model with the lowest water consumption, maximum power generation or peak peaking efficiency, and use the optimization method to solve and formulate a reasonable control method. This paper only studies the issue of power generation planning in the final water level control mode.

2.1 Objective Function

2.1.1 Minimum Grid Residual Variance

In order to give full play to the peaking of hydropower units, the short-term power generation plan should minimize the peak-valley difference of the remaining load of the power grid, and make the remaining load process as flat as possible, so as to achieve safe and stable operation of the power grid. Here, the minimum variance of the grid residual is the objective function, and the formula is as follows:

$$\begin{cases} D_t = C_t - \sum_{i=1}^I N_t^i \\ \bar{D} = \frac{1}{T} \sum_{t=1}^T D_t \\ \min F = \frac{1}{T} \sum_{t=1}^T (D_t - \bar{D})^2 \end{cases} \quad (1)$$

Where i is the serial number of the power station; $i \in [1, I]$; t is the serial number of the time zone, $t \in [1, T]$; respectively, C_t and D_t are the grid load and the rest of the t -th period; N_t^i is the output of the power station i at the t -th period; \bar{D} and F are the statistical values, which represents the average value of the grid residual and its variance.

2.1.2 The largest Cascade total generation

The short-term power generation planning of cascade hydropower stations usually gives the initial and final water levels, that is, the daily power generation plan of each hydropower station is established under the condition that the available water quantity is known, which belongs to the category of the largest total power generation and the least load variance. Therefore, the

maximum generation of cascades is a consideration. The objective is calculated as follows:

$$\begin{cases} \max E = \sum_{i=1}^I \sum_{t=1}^T N_t^i \cdot \Delta t \\ N_t^i = \sum_{m=1}^M N_{t,m}^i(q_{t,m}^i, H_{t,m}^i) \end{cases} \quad (2)$$

Where, M represents the number of units of the i -th power station, and $N_{t,m}^i$ represents the output of the m -th unit of the power station i during the t -th period, which is a function of the power generation flow $q_{t,m}^i$ of the unit and the generating head $H_{t,m}^i$.

2.2 Constraint Condition

(1) Final Water Level Constraint

$$Z_{T+1}^i = Z_{end}^i \quad (3)$$

Where Z_{T+1}^i and Z_{end}^i respectively represent the actual water level of the power station and the final water level of the control.

(2) Water Level Constraint

$$Z_{t,\min}^i \leq Z_t^i \leq Z_{t,\max}^i \quad (4)$$

Where, Z_t^i , $Z_{t,\max}^i$ and $Z_{t,\min}^i$ respectively represent the water level and the upper and lower limits of the power station i during the t -th period.

(3) Power Constraint

$$N_{t,\min}^i \leq N_t^i \leq N_{t,\max}^i \quad (5)$$

Where, N_t^i , $N_{t,\max}^i$ and $N_{t,\min}^i$ respectively represent the output of the power station i and its upper and lower limits during the t -th period.

(4) Discharge Volume Constraint

$$Q_{t,\min}^i \leq Q_t^i \leq Q_{t,\max}^i \quad (6)$$

Where, Q_t^i , $Q_{t,\min}^i$ and $Q_{t,\max}^i$ respectively represent the discharge volume and its upper and lower limits of the power station i during the t -th period.

(5) Water Balance Constraint

$$V_{t+1}^i = V_t^i + (I_t^i - Q_t^i) \cdot \Delta t \quad (7)$$

Where, V_t^i and V_{t+1}^i respectively represent the initial and final storage values of the power station i during the t -th period; I_t^i and Q_t^i respectively represent the storage and discharge of the power station i during the t -th period; Δt is the length of the period.

(6) Output Ramping Constraint

$$\left| N_t^i - N_{t-1}^i \right| \leq R^i \quad (8)$$

Where R^i is the limit of the single-period output ramping of the power station i .

(7) Unit Vibration Zone Constraint

$$(N_{t,m}^i - N_{m,\min}^i) \cdot (N_t^i - N_{m,\max}^i) \geq 0 \quad (9)$$

Where, $N_{m,\max}^i$ and $N_{m,\min}^i$ are the upper and lower limits of the vibration zone of the m-th unit of the power station i , respectively.

3 Research on Efficient Algorithm of Model

Different from the medium and long-term optimal dispatching of cascade hydropower stations is only related to the power station level, the short-term planning usually needs to be refined to each unit, and the constraints such as ramping limit, unit maintenance plan and output vibration area need to be considered, and the model calculation is more complicated. This paper introduces the method of optimal allocation of flow using dynamic programming. Based on the random generation of initial solution and infeasible solution repair strategy, SMPSO is used to solve the short-term multi-objective power generation planning model. The ramping, output vibrations areas and other constraints are processed.

3.1 Spatial Flow Optimal Allocation Method

The calculation of water energy needs to consider the change of the efficiency of the hydroelectric generating unit. The medium and long-term scheduling is generally estimated by the output coefficient method (K-value method). As the accuracy requirements of the power system for short-term power generation plans are getting higher and higher, the K-value method can no longer meet the actual engineering needs. Based on the NHQ curve of the unit, the optimal power characteristics of the entire plant should be calculated and the errors should be reduced as much as possible, improving the accuracy of power generation planning.

According to different input conditions, the economic operation mode of hydropower stations has two modes: "set water volume by electric quantity" and "set electric quantity by water volume". Under the "set water volume by electric quantity" mode, the hydropower station load and the unit dynamic characteristics are known. The penalty function method is used to deal with the vibration zone constraints of the unit, and the economic operation plan and the optimal distribution output process of each unit are formulated. Using the dynamic programming method, the corresponding recursion formula is as follows:

$$\begin{cases} Q_k^*(\bar{N}_k, H) = \min [Q_k(N_k, H) + Q_{k-1}(\bar{N}_{k-1}, H)] \\ \bar{N}_{k-1} = \bar{N}_k - N_k \\ Q_0^*(\bar{N}_0, H) = 0 \end{cases} \quad (10)$$

Where, k is the unit number, $k \in [1, k]$; H is the power net head; \bar{N}_{k-1} and \bar{N}_k are the total loads under (k-1)-th and k-th units, respectively; $Q_k^*(\bar{N}_k, H)$ is the

optimal total flow of each unit under total load \bar{N}_k and net head H ; $Q_k(N_k, H)$ is the consumption flow when the output of the k-th unit is N_k ; $Q_0^*(\bar{N}_0, H)$ is the boundary condition.

According to the above method, the optimal load distribution scheme under the combination of all the head H and the output N is solved in turn, and the optimal load distribution table of the power station can be obtained, and the direct metering can be performed when calculating the "set water volume by electric quantity", which generally satisfies the actual engineering accuracy. "set water volume by electric quantity" can effectively deal with the constraints of the output vibration zone, and obtain the optimal power characteristic curve of the whole plant. It is widely used and can be converted into "set electric quantity by water volume" regardless of the head loss of the unit. When calculating "set electric quantity by water volume", it is necessary to perform an iterative search for the known power consumption in combination with the half-search method. The specific steps are as follows:

Step1: Calculate the net head of the power station, check the expected output curve of the power station under the given water head, obtain the maximum output N_{\max} and minimum output N_{\min} of the power station, and find the corresponding power generation flow Q_{\max} and Q_{\min} .

Step 2: Determine whether the known discharge flow Q is between Q_{\min} and Q_{\max} . If $Q < Q_{\min}$, set the final output $N=0$; and go to Step5; if $Q > Q_{\max}$, set the final output $N = N_{\max}$, and go to Step5; otherwise, go to Step3 to perform a half-find search.

Step3: Order $N' = \frac{(N_{\min} + N_{\max})}{2}$, use the "set

water volume by electric quantity" mode to obtain the total flow volume Q' of the power station under the output.

Step4: If $|Q - Q'| \leq \delta$, set the final output $N = N'$, go to Step5; if $Q - Q' > \delta$, showing the N' is too small, setting $N_{\min} = N'$ and going to Step3 to continue iteration; if $Q' - Q > \delta$, showing the N' is too large, setting $N_{\max} = N'$ and going to Step3 to continue iteration;

Step5: The iteration ends and the final output is N .

3.2 Multi-Objective Particle Swarm Optimization Algorithm and Its Improvement

Particle Swarm Optimization (PSO) is an intelligent optimization algorithm jointly proposed by American scholars Kennedy and Eberhart. It optimizes the optimal solution to be searched by simulating the foraging behavior of birds, and has the ability of collaborative search and group search. Different from other

evolutionary algorithms, PSO uses speed and position update strategies and its own and global memory capabilities to avoid complex crossovers, mutations and other operations. Its speed and position update formula is as follows:

$$\vec{v}_i(t) = w \cdot \vec{v}_i(t-1) + C_1 \cdot r_1 \cdot (\vec{x}_{p_i} - \vec{x}_i) + C_2 \cdot r_2 \cdot (\vec{x}_g - \vec{x}_i) \quad (11)$$

Where, w is the inertia weight; C_1 and C_2 are positive acceleration constants; r_1 and r_2 are random numbers uniformly distributed between $[0, 1]$. x_{p_i} represents the individual extrema of the i -th particle; x_g is the global extremum; $v_i(t)$ represents the velocity after the particle is updated.

$$\vec{x}_i(t) = \vec{x}_i(t-1) + \vec{v}_i(t) \quad (12)$$

In the formula (12), $x_i(t-1)$ and $x_i(t)$ respectively indicate the positions before and after the particle is updated.

In order to effectively use the particle swarm algorithm framework to solve multi-objective optimization problems, scholars at home and abroad have carried out a lot of research, and the results are quite fruitful. Coello, etc proposed multi-objective particle swarm optimization (MOPSO) for the first time based on external archives and adaptive grid method. Sierra et al. improved MOSPO and introduced the concept of crowded distance and polynomial variation. The efficiency of the algorithm is solved. Nebro et al. made further improvement by using the optimization strategy of limiting particle flight velocity and the SMPSO algorithm was proposed, which has two aspects: the solution quality of the non-dominated solution set and the convergence speed of the Pareto frontier. SMPSO uses a compression factor to eliminate the boundary limit of velocity, and the corresponding velocity calculation formula is changed from :

$$\vec{v}_i(t) = \chi \left(w \cdot \vec{v}_i(t-1) + C_1 \cdot r_1 \cdot (\vec{x}_{p_i} - \vec{x}_i) + C_2 \cdot r_2 \cdot (\vec{x}_g - \vec{x}_i) \right) \quad (13)$$

$$\chi = \frac{2}{2 - \varphi - \sqrt{\varphi^2 - 4\varphi}} \quad (14)$$

$$\varphi = \begin{cases} C_1 + C_2 & \text{if } C_1 + C_2 > 4 \\ 1 & \text{otherwise} \end{cases} \quad (15)$$

Where, χ is the compression factor; φ is the control parameter.

In addition, when the speed is out of bounds, the corresponding correction strategy is:

$$v_{i,j}(t) = \begin{cases} \Delta_j & \text{if } v_{i,j}(t) > \Delta_j \\ -\Delta_j & \text{if } v_{i,j}(t) \leq -\Delta_j \\ v_{i,j}(t) & \text{otherwise} \end{cases} \quad (16)$$

$$\Delta_j = \frac{U_j - L_j}{2} \quad (17)$$

Where $v_{i,j}(t)$ represents the velocity of the j -th dimension variable of particle i ; U_j and L_j are the upper and lower limits of the velocity of the j -th dimension, respectively.

Unlike the traditional MOEA algorithm, SMPSO does not require a process of fitness assignment, and the algorithm design is simplified accordingly. However, since there are multiple global optimal solutions that are not dominated by each other, SMPSO randomly selects two solutions from the external file set, and obtains the global extremum by comparing the crowded distances of the two. In addition, in order to prevent the algorithm from falling into local optimum, SMPSO uses polynomial variation to mutate 15% of the particles.

SMPSO solves the short-term multi-objective power generation planning problem. The reservoir water level is also selected as the decision variable to encode the particles. The ‘‘corridor’’ method is used to randomly generate the initial solution and the infeasible solution repair strategy, and the single-period is based on the spatial optimal flow distribution method. Correct the output process that does not meet the ramping constraints. Taking two adjacent time periods as an example, for the positive ramping constraint, select the appropriate step size to gradually reduce the end water level of the first time period, recalculate the force, and iterate until the output of the two time periods satisfies the rising limit; The method of climbing slope constraint processing is reversed and will not be described again.

In summary, the process of SMPSO solving multi-target short-term power generation planning problem is shown in Figure 1. The steps are as follows:

Step1: Initialize the particle swarm. N particles are randomly generated in the feasible space, and their speed is initialized; the objective function value of each particle is calculated.

Step 2: Determine the initial individual extremum of each particle, the initial position of each particle itself.

Step3: According to the dominance relationship of the particles, some particles that are not dominated by each other are obtained and stored in the external archive set NP.

Step 4: Update the position and velocity of each particle according to formulas (11) and (12).

Step 5: Randomly select 15% of the particles for polynomial variation.

Step6: Use the repair strategy to fix the infeasible solution and calculate the objective function value of all particles again.

Step7: Update the particle's own best position p_{best} .

If the new solution p_{best} is dominant, the replacement is performed; if the new solution is not dominated by each other, a solution is randomly selected as the new one.

Step 8: Update and maintain the NP according to the dominant relationship of the particles and the crowded distance.

Step 9: Determine whether the termination condition is satisfied. If so, output the external file set NP; otherwise, go to Step 4 to continue the iteration.

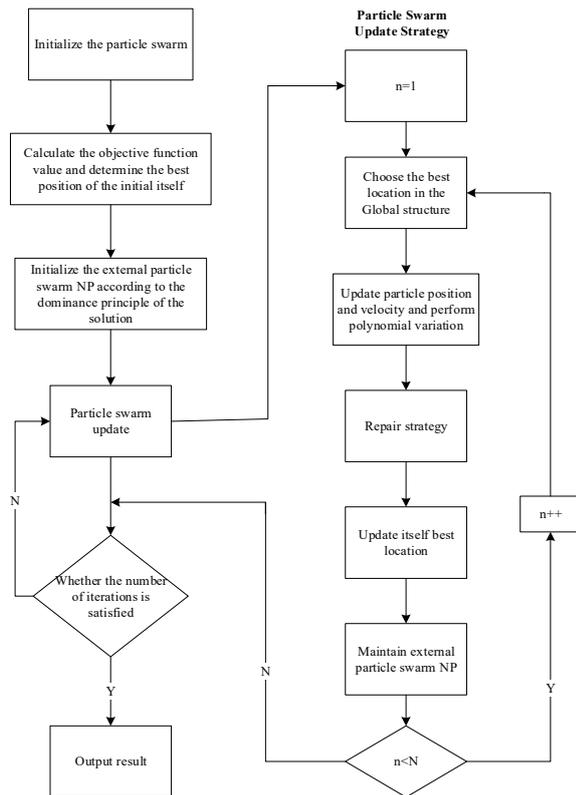


Figure 1. SMPSO Flow Chart.

4 Case study and analysis

In order to verify the rationality and effectiveness of SMPSO in solving the short-term multi-objective power generation plan of cascade hydropower stations, the paper takes Qingjiang cascade as an example. The Qingjiang cascade includes Shuibuya, Geheyan and Gaobazhou hydropower stations with a total installed capacity of 3.322 million kilowatts and a designed annual power generation of 7.923 billion kWh. It has good peak shaving

and frequency modulation effects and stable operation is of great significance for Huazhong Power and Hubei Grid. The main engineering characteristic parameters are shown in Table 1.

The actual operating conditions of the Hubei Province and Qingjiang cascades were selected on a certain day in 2014, and the SMPSO algorithm was used to solve the short-term multi-object power generation scheduling model. On that day, the load peak-valley difference of Hubei Province was 2,421,800 kW, and the variance was 5,506.10; the water level of the Shuibuya Power Station was 381.23m and 381.17m respectively, and the water level of the Geheyan Power Station was 193.62m and 193.56m, respectively. The water level at the beginning and end of the power station is 78.75m and 78.67m respectively. The output vibration area of each power station unit is shown in Table 1. In addition, the maximum output of a single unit is set by the single-time output ramping constraint. The parameters of the SMPSO algorithm are set as follows: acceleration constant $C_1, C_2 \in [1.5, 2.5]$; inertia weight $w = 0.1$; polynomial

variation parameter $p_m = \frac{1}{K}$, which K is the number of

variables, $\eta = 20$; the size of the particle group and the external archive set are 100; the iteration number is 2000 generation. As a comparison, the OMOPSO algorithm is selected for calculation, and the corresponding parameters are set as: acceleration constant $C_1, C_2 \in [1.5, 2.0]$; inertia weight $w \in [0.1, 0.5]$; uniform variation and non-

uniform mutation probability $p = \frac{1}{K}$, among which k is

the number of variables; the particle swarm size and the number of iterations are the same as the SMPSO algorithm.

Table 1 Qingjiang Cascade Hydropower Station Characteristic Parameter Table.

Power Station Name	Normal Water Level (m)	Dead Water Level (m)	Adjustment Ability	Installed Capacity ($\times 10^4$ kW)	Number of Units	Unit Vibration Zone ($\times 10^4$ kW)
Shuibuya	400	350	Years of Adjustment	184	4	15~30
Geheyan	200	160	Annual Adjustment	120	4	8~18
Gaobazhou	80	78	Day Adjustment	27	3	Null

Table 2 Pareto Optimal Solution set Distribution of the Qingjiang Cascade Multi-Objective Short-Term Power Generation Plan

Scheme Number	Scheduling Target		Scheme Number	Scheduling target	
	Residual variance	Cascade Total Power Generation ($\times 10^4$ kWh)		Residual Vaeiance	Cascade Total Power Generation ($\times 10^4$ kWh)
1	990.12	2315.584	26	1407.06	2359.665
2	991.87	2317.521	27	1426.81	2362.947
3	991.98	2322.797	28	1443.44	2363.121

4	1000.76	2323.945	29	1461.46	2363.561
5	1006.95	2324.577	30	1491.57	2365.174
6	1021.03	2326.318	31	1521.88	2365.258
7	1027.29	2327.649	32	1534.71	2368.324
8	1030.31	2328.528	33	1541.58	2369.029
9	1042.65	2329.74	34	1586.73	2370.107
10	1055.11	2330.159	35	1611.1	2373.088
11	1061.59	2330.738	36	1649.27	2374.842
12	1066.36	2332.525	37	1665.33	2375.867
13	1080.29	2333.914	38	1678.46	2378.749
14	1087.9	2335.559	39	1711.57	2379.747
15	1104	2336.812	40	1745.86	2380.459
16	1110.14	2337.427	41	1755.47	2380.778
17	1133.74	2337.696	42	1786.44	2384.454
18	1148.84	2339.793	43	1880.29	2388.652
19	1182.11	2341.06	44	2070.35	2390.506
20	1207.73	2342.104	45	2186.86	2391.978
21	1227.05	2347.845	46	2207.47	2393.107
22	1262.46	2351.38	47	2280.31	2394.116
23	1319.56	2354.387	48	2377.04	2395.178
24	1350.77	2358.067	49	2445.3	2395.408
25	1382.15	2358.913	50	2450.63	2395.551

Table 3 Comparison of the Results of the Qingjiang Cascade Multi-Objective Power Generation Plan

Program	Variance	Variance Decline	Peak- Valley Difference ($\times 10^4$ kW)	Peak-Valley Difference Rate	Power Generation ($\times 10^4$ kWh)
Original Load	5506.10	-	242.18	-	-
Option 1 (Minimum Variance)	990.12	82.0%	130.97	45.9%	2315.584
Option 50 (Maximum Total Power Generation)	2450.63	55.5%	174.07	28.1%	2395.551

Taking the daily scheduling period (24 time periods), the simulation calculation of the multi-objective power generation plan for the Qingjiang cascade hydropower station is carried out, and the Pareto frontier and the optimal solution set distribution are shown in Figure 2 and Table 2. Due to space limitations, only 50 uniformly distributed non-dominated solutions are listed here. It can

be seen from the results that the total power generation of the cascade is positively correlated with the variance of the grid residual power, that is, the smaller the variance of the grid residual, the flatter the residual, the better the peaking efficiency, and the smaller the total power generation of the cascade, indicating the peaking benefit and power generation benefit. It is mutually restrictive. In

response to the peaking demand of the power grid, the power stations of the cascades increase their output at the peak of the load, reduce the output operation at the low load, break the original optimal power generation plan, and reduce the total power generation of the cascade.

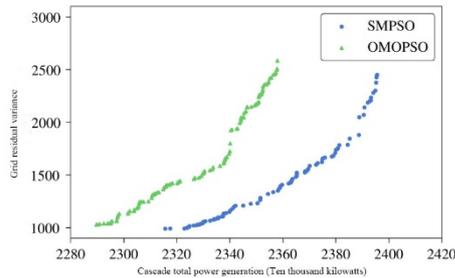


Figure 2. Different Algorithms to Solve the Pareto Frontier of Generation Planning.

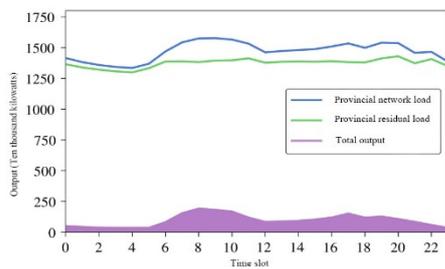
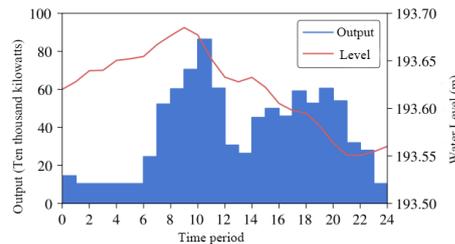
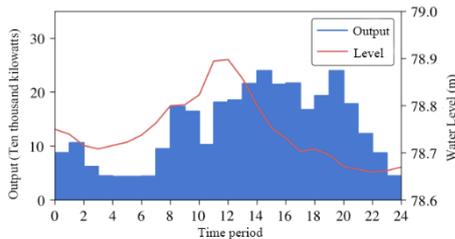


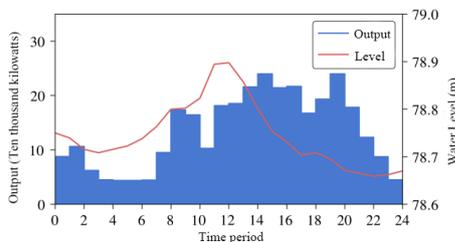
Figure 3. Cascades Output Process and Provincial Residual Results of Scheme 1.



(a) Shuibuya



(b) Geheyan



(c) Gaobazhou

Figure 4. Cascade Output Process and Provincial Residual Results of Scheme 1.

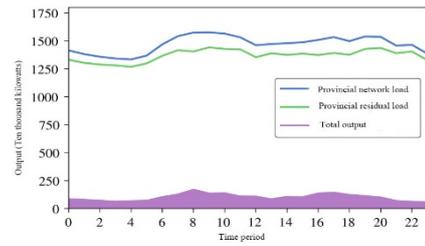
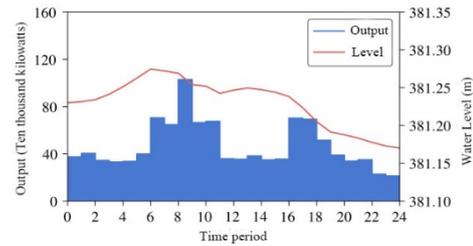
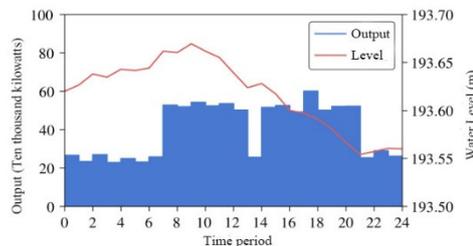


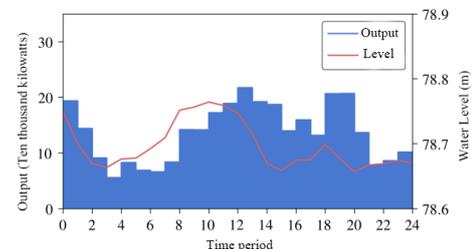
Figure 5. Cascade Output Process and Provincial Residual Results of Scheme 50.



(a) Shuibuya



(b) Geheyan



(c) Gaobazhou

Figure 5. Water Level and Output Process of Cascade Station of Scheme 50.

Table 3 lists the comparison results of the indicators under the two extreme scenarios of the minimum residual power of the provincial network and the maximum total power generation of the cascade. The former is the scheme 1, and the optimized load results are shown in Figure 3. The water level and output process curves of the Qingjiang cascade power stations are shown in Figure 4; the latter is the scheme 50, the corresponding optimization results, the water level and output process of the cascades are shown in Figures 5 and 6.

It can be seen from Table 3 that the residual variance of the scheme 1 is reduced from the original 5506.10 to 990.12, with a drop of 82.0%; the peak-valley difference is reduced from the initial 2,421,800 kW to 1,309,700 kW, correspondingly reduced by 45.9%. Peak benefits are significant. Through the regulation of the Qingjiang cascade hydropower station, the balance of the provincial network tends to be stable, and the peaking effect of hydropower is fully exerted. The variance of the residual

budget of the 50 provinces is 2,540.63, a decrease of 55.5%; the difference between the peaks and valleys is 1,740,700 kW, a corresponding decrease of 28.1%, and there is a certain peaking effect, but there is still a situation of residual fluctuations. The total power generation of the cascade in the scheme 1 is 235,554,000 kWh, and the scheme 50 is 239.555 million kWh, which is 3.5% higher than that of the scheme 1. This is the result of the loss peaking benefit, which further proves that the power generation benefit and the peaking benefit are mutually constrained.

In addition, from the water level and output process of the Qingjiang cascade power stations, the water level at the end of each power station dispatching period has reached a given final water level, and the water level process has changed smoothly, meeting the daily and hourly variable amplitude constraints. Each power station with low grid load is powered by the minimum discharge, and the output is increased to meet the peaking demand. The calculation result is reasonable and effective. In the actual power generation planning process, it is necessary to comprehensively balance the two objectives of peaking efficiency and power generation efficiency, and select the final solution from the Pareto non-dominated solution set.

5 Conclusion

In this paper, the short-term multi-objective power generation planning problem of cascade hydropower stations in the basin is studied. The model of considering the minimum residual variance and the total power generation of cascades is established. The improved multi-objective particle swarm optimization (SMPSO) algorithm is used to solve the model efficiently. The results of the Qingjiang cascades like Shuibuya, Geheyan and Gaobazhou power stations show that SMPSO can effectively deal with complex constraints, improve the quality and solution speed of Pareto optimal solution set, and improve the response to the peaking demand of the power grid. The power generation benefit of the entire cascades can provide reference for the short-term power generation scheduling of cascades, and has certain engineering application value.

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