Optimal Operation Study of Qing River Cascade Reservoirs Based on GA with Uncertainty and Flow Transmission Considered

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Abstract

This paper presented a simulation method which considers the uncertainty and flow transmission in optimal operation of Qing River cascade reservoirs. Latin hypercube method was applied to simulate the uncertain inflow, and its sampling frequency and accuracy were very satisfied. Linear regression method was used to deal with the damping and deformation in the process of flow transmission. And Genetic algorithm (GA) was found application for solving the optimal operation model of Qing River cascade reservoirs. According to the method presented, we could obtain the scheduling scheme of cascade reservoirs under different risk rates which were helpful to the decision-making. The result showed that the method is practical.

Keywords: Qing River cascade reservoirs; Latin hypercube; Flow transmission; Linear regression method; Genetic algorithm

1. Introduction

In recent years, many scholars propose the following methods such as probability method [1-2], stochastic differential equation [3] and stochastic simulation method [4] to deal with the random problem. But the research on the uncertainty of optimal operation of cascade reservoirs is seldom. In this paper, Latin hypercube method is applied to the uncertainty analysis of reservoir inflow. In more recent works, the transmission system requires higher computational effort and generally adopts some sort of decomposition approach [5] and this paper uses linear regression method to dispose of hydraulic

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Genetic algorithm is applied to solve the optional operation of Qing River cascade reservoirs.

**Nomenclature**

- $Q_i$: power generation flow of the station $i$ in the period $t$ (m$^3$/s)
- $H_i$: running head of the reservoir $i$ in the period $t$ (m)
- $Q_{in}, Q_{out}$: inflow, abandoned and outflow flow of the reservoir $i$ in the period $t$ (m$^3$/s)
- $V_i, Z_i$: water storage and water level of the reservoir $i$ in the period $t$
- $Q_{min}, Q_{max}$: the minimum and maximum release flow of the reservoir $i$ in the period $t$ (m$^3$/s)
- $Z_{min}, Z_{max}$: the minimum and maximum limited water level of the reservoir $i$ in period $t$ (m)
- $N_{min}, N_{max}$: the minimum and maximum allowable output of the reservoir $i$ in the period $t$ (10$^4$kW)
- $q_{int}$: interval inflow between reservoir $i$ and reservoir $i'$ in the period $t$
- $\alpha, \beta$: propagation coefficient related to the outflow of reservoir $i$
- $\gamma$: linear correlation coefficient
- $Q_{outSB}, Q_{outGH}$: outflow of Shuibuya and Geheyan
- $Q_{inSB}, Q_{inGH}$: inflow of Geheyan and Gaobazhou
- $N_i$: output of the station $i$ in the period $t$ (10$^4$kW)

2. Uncertainty analysis and simulation

2.1 Uncertainty analysis

This paper pays attention to single factor simulation method under consideration of reservoir inflow. Suppose $Q_f$ is the foreseen inflow in the forecast period, and $Q_a$ is the actual inflow, it is the risk events when $Q_a < Q_f$, the risk rate is remarked as equation (1):

$$P = P(Q_a < Q_f) = \int_{0}^{Q_f} f(Q)dQ$$  \hspace{1cm} (1)

2.2 Simulation method

Step 1. Suppose $x$ is the random variable. Arrange the measured value from small to large, select several sub-spaces, fix the rang to make the probability of each sub-space equal, then the sub-space $m$’s cumulative probability can be calculated as equation (2):

$$F(x) = \int_{0}^{x} f(x)dx = m/M \hspace{1cm} (2)$$

Step 2. Produce several (several=M) variable $\mu (i=1,2...,M)$ who follow uniform distribution from 0 to $1/M$, expressed as $\mu \sim U(0,1/M)$.

Step 3. Calculate the probability distribution sequence as equation (3):
\[ P_i \ (i = 1, 2, ..., M) : P = (i - 1)/M + \mu_i \]  

(3)

Step 4. Calculate the random variables as equation (4):

\[ x = F(P) \]  

(4)

Step 5. Output the simulation variable.

2.3. Inflow simulation of Qing River

The sample size is 1000. And the simulation results at 8:00 am of April 14th, 2011 are shown Fig. 1.

![Fig. 1 Comparison of distribution of measured and simulation inflow sequence](image)

3. Optimal operation model and GA

3.1 Objective function

The maximum power generation is given by: 

\[ MaxE = \sum_{i=1}^{\Delta t} \sum_{n=1}^{T} N_i^t \cdot \Delta t = \sum_{i=1}^{\Delta t} \sum_{n=1}^{T^n} K_i \cdot Q_i \cdot H_i \cdot \Delta t \]  

(5)

3.2 Constraints

Water balance constraint:

\[ Q_{in} + (V_i - V_{in})/\Delta t = Q_{out} \]  

(6)

Release constraint:

\[ Q_{min} \leq Q_i \leq Q_{max} \]  

(7)

Water level constraint:

\[ Z_{min} \leq Z_i \leq Z_{max} \]  

(8)

Output constraint:

\[ N_{min} \leq N_i \leq N_{max} \]  

(9)

3.3. Algorithm design of GA

a. Individual coding. This paper designs real coding in the allowed range of the water level, see equation (10):

\[ Z_i = Z_{min} + \text{int}(\text{int}(Z_{max} - Z_{min})/\lambda + 1)) \times Rnd \times pop \]  

(10)

b. Generate initial population. Generate \( pop \) sets of water level sequences in the feasible region randomly which can be expressed as:

\( (Z_{11}, Z_{12}, ..., Z_{1n}), (Z_{21}, Z_{22}, ..., Z_{2n}), ..., (Z_{m1}, Z_{m2}, ..., Z_{mn}) \)

c. Fitness function. The objective function is set to be the fitness function to identify individual strengths and weaknesses.
d. Genetic manipulation. In this paper we use the most commonly used roulette selection method. The restricted one-point crossover method is adopted to generate new individuals and Non-uniform mutation is applied to improve local search ability.

4. Flow transmission

Builds a linear regression equation using the measured data aiming at transmission coefficient calibration between the upstream station outflow and downstream reservoir inflow, we get two equations.

\[ Q_{\text{out}} = 1.2564Q_{\text{in}} + 16.456 \quad \gamma' = 0.803 \]  
\[ Q_{\text{out}} = 1.0257Q_{\text{in}} + 18.118 \quad \gamma' = 0.912 \]

5. Optimal results

Qing River cascade reservoirs, composed by Shuibuya, Geheyan, Gaobazhou hydropower stations, are located in Hubei Province. The individual is 24, population is 100, selection probability is 0.2, and they evolve 500 times, and the optimal results of April 14th, 2011 are shown in table 1, figure 2 and figure 3.

| P (%) | 5   | 10  | 20  | 30  | 40  | 50  | 90  |
|-------|-----|-----|-----|-----|-----|-----|-----|
| Shuibuya | 500.6 | 546.7 | 617.5 | 691.3 | 797.3 | 1044.1 | 4416 |
| Geheyan | 453.6 | 495.1 | 553.1 | 600.7 | 635.1 | 819.8 | 2908.8 |
| Gaobazhou | 162.5 | 174.5 | 183.3 | 205.7 | 213.4 | 265.2 | 648 |
| Gross generation | 1116.7 | 1216.3 | 1353.8 | 1497.7 | 1645.8 | 2129.2 | 7972.8 |

Figure 2. Power generation process when P=10% (left)
Figure 3. Power generation process when P=50% (right)

6. Conclusion

This research uses the random simulation method of single factor to deal with the uncertainty problem of reservoir inflow. It changes the complex decision-making of stochastic problem into that of determinable operation, and provides a new way for uncertainty analysis of power generation scheduling of cascade reservoirs.

In the random simulation, Latin Hypercube sampling method is used to stratify the random variable, which improves Monte Carlo simulation method. The results that of traditional sampling method, thus the simulation performance is much better and more realistic.
Applying linear regression method, the optimal operation model of Qing River cascade reservoirs considers the flow transmission between the upstream station and the downstream one, and the results is more realistic than that in the situation of not considering the impact of flow transmission.

Except forecasting errors, optimal operation of Qing River cascade is also affected by other uncertainties, such as hydropower operating conditions, the unit's maintenance, the state at the initial and the final time and so on. Thus, the uncertainty of generation scheduling remains to be studied further.

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