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Research paper

Study on the optimal hydropower generation of Zhelin reservoir

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Abstract

Zhelin reservoir, a multi-purpose reservoir designed mainly for hydropower generation, is located in Xiushui watershed in Jiangxi Province, China. As the rainfall has a decreasing trend in recent years, the reservoir storage capacity cannot be fully filled and the original operation rule can no longer fulfill the desired target for power production. In order to ensure the dam safety and produce more economic benefits from hydropower generation, the original operation rule of the reservoir needs to be evaluated for possible improvement to yield optimal benefits. In this study three optimization algorithms including progressive optimization algorithm (POA), particle swarm optimization (PSO) and genetic algorithm (GA) are applied. According to a long discharge data series, the minimization of water consumption rate is chosen as the objective function, along with several physical and operational constraints. After comparing the results of the three methods, POA is found more suitable for Zhelin reservoir. Sensitivity of the optimization algorithms is also analyzed, of which, the step size of water level of the reservoir for POA, the initial population sizes for PSO and GA are also explored to search for the most suitable parameters. The investigation further reveals that step size 0.01 m, population size 50 and 30 are the best choice for POA, PSO and GA, respectively.

Keywords: Hydropower generation; Optimal operation; Progressive optimization algorithm; Particle swarm optimization; Genetic algorithm; Sensitivity

1. Introduction

In consideration of economic development and environmental preservation, factors to be considered in reservoir operations are increasing and the demand on reservoir management becomes increasingly higher. Traditional management scheme can no longer cope with today's various demands on reservoirs. Application of system analysis theory to water resources planning for optimizing reservoir operation has been an important research area for purpose of taking full advantage of regulating reservoir storage capacity and maximizing economic benefits. At the same time, the constraints on operation should be considered such as outlet and storage capacities (Mays and Tung, 2002). Numerous studies highlight the main concerns in reservoir operation by reservoir operators and researchers.

Since the early 1950's, optimal scheduling theories applied to reservoir operation have been studied. Masse (1946) firstly introduced the concept of optimization to reservoir operation in which stochastic dynamic programming was used to search for optimal operation of reservoirs. While a large number of researches have been done, various reservoir optimal scheduling models aiming at different issues also emerged along with the continuous development of the system theory, especially in the 1970's and 1980's. At present, the widely used methods for optimal reservoir operations include linear programming (LP), dynamic programming (DP), nonlinear programming (NLP), and some new intelligent global optimization algorithms (Schoukens et al., 2004).

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As the reservoir operation is a multi-stage decision problem, DP has been the most widely used. However, when DP is applied to the optimization of a reservoir system with complicated configurations, the state space will be multi-dimensional rendering drastic increase in required computation time and computer memory – the "curse of dimensionality". To overcome this problem, many improved methods have been developed, such as the progressive optimization algorithm (POA). Howson and Sancho (1975) proposed a POA to solve a multi-state DP problem, which was later improved by Zhang and Bai (1987) to the state extreme progressive optimization algorithm (SEPOA). Fan and Li (1996) used the POA in the progressive approach algorithm (PAA), called PAPOA, to search for the optimal solution.

One of the significant developments in modern science and technology is the overlap of life sciences and engineering sciences which interweaves and promotes one another. Simulating the behavior of biological groups to solve computational problems has gradually formed swarm intelligence (SI) as the main research topic in theoretical systems analysis. Many researchers studied the mathematical modeling and computer simulation on the self-organization of group-type organisms (colony, bees, birds, etc.), which produced the swarm intelligence. Kennedy and Eberhart (1995), inspired by the foraging behavior of birds, proposed the particle swarm optimization (PSO). Later, Shi and Eberhart (1998) introduced the inertia weight in the evolution equation to improve its convergence. They pointed out that a larger inertia weight is better for the global search of particle swarm, while a smaller inertia weight favors the local search. Abido (2002) used a PSO to solve the optimal power flow problem. Meraji et al. (2005) applied PSO to reservoir operation. Kumar and Reddy (2007) presented an elitist-mutated particle swarm optimization (EMPSO) technique to derive operation policies of multi-objective reservoir systems. EMPSO showed a favorable result when compared with the normal PSO. Alexandre and Darrell (2008) used the multi-objective PSO in water resources management. As the water resources management presents a large variety of multi-objective problem, a multi-objective particle swarm optimization (MOPSO) would be suitable.

John and Bagley (1967) presented the word "genetic algorithm"(GA) in his doctoral thesis, in which the genetic manipulations such as copy, crossover, mutation, dominant, inversion and others form the origin of the genetic algorithm. Srinivas and Patnaik (1994) proposed to use adaptive crossover and mutation to achieve two objectives: (1) keep the diversity of the population; and (2) guarantee the convergence of genetic algorithms. Since the mid 1980s genetic algorithms were improved rapidly and it has been applied to adaptive behavior, artificial intelligence, neural networks, robotics, operations research, artificial life, etc. Oliveira and Loucks (1997) used GA to derive the multi-reservoir operating policies. GA took real-valued vectors to define the system's conditions by using iteration functions. Wardlaw and Sharif (1999) presented the evaluation of GA to optimal reservoir system operation which showed that the use of real-value coding converges significantly faster than binary coding. Chang and Fi-John (2001) presented a new GA-based approach to real-time reservoir operation. Jothiprakash and Shanthi (2006) applied GA to obtain optimal operation rules in single reservoir operation problem. Shirangi et al. (2008) developed a simplified algorithm combining with a multi-objective genetic algorithm for reservoir operation.

Many studies on climate change have shown that global warming and change in precipitation patterns (both in intensity and variability) are already observable (James et al., 2006; Gemmer et al., 2004). The operation system for Zhelin reservoir based on the conventional operation scheme cannot meet the goal of optimal hydropower generation, and the benefits of the hydropower plant are reducing gradually. The objective of this study is to propose an optimal scheduling of Zhelin reservoir to make full use of water resources and create more economic benefits.

2. Optimal models for hydropower generation

2.1. Determination of hydropower

Energy is produced by passing water through turbines. Hydropower generation by a turbine can be calculated by

$$\begin{cases} N = Kq\Delta H \\ Q - q = \dfrac{\Delta V}{\Delta t} \end{cases} \tag{1}$$

where N is the hydropower output (in kw); K is the coefficient having a value of 8.3 for large and medium hydropower plant in China; Q and q (in m^3/s) are the inflow to and outflow from the turbine, respectively; ΔH is the water head (in m); ΔV (in m^3) is the storage volume change of the reservoir; and Δt (in s) is the time step of operation. From Equation (1), it can be seen that water head and outflow are the two basic elements affecting the dynamic characteristics of hydropower station.

For a period of one year, the electricity of power generation can be calculated by

$$E_y = \sum_{m=1}^{12} N_{m,y} \Delta t_{m,y} \tag{2}$$

in which, E_y is the electricity generated each year (in kwh); $\Delta t_{m,y}$ (in h) is the time period of hydropower generation in the m-th month of the y-th year; $N_{m,y}$ is the hydropower output in the m-th month of the y-th year (in kw).

2.2. Constraints

(1) Water balance constraints:

$$V_{m+1} = V_m + (Q_m - q_m - D_m)\Delta t_m \tag{3}$$

in which, V_m and V_{m+1} are the initial and final storage volumes of the reservoir in the duration Δt_m, respectively; Q_m, q_m and D_m are the inflow, outflow and controlled release