International Journal of Software Innovation
Volume 7 • Issue 1 • January-March 2019

Optimal Operation of Multireservoir Systems by Enhanced Water Cycle Algorithm

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ABSTRACT

In this article, an enhanced water cycle algorithm (EWCA) is proposed and applied to optimize the operation of multireservoir systems. Three improvements have been made to the water cycle algorithm (WCA). They refer to high-quality initial solutions obtained by the chaos-based method, balancing of exploration of streams using a dynamic adaptive parameter, and dynamic variation of sub-water system size using the fitness value of rivers. For the purpose of verifying the improvements, three typical benchmark functions were selected as test functions. It has shown that EWCA performs better than WCA and water cycle algorithm with evaporation rate (ER-WCA). And then these three algorithms were also applied to optimize the operation of a multireservoir system with complex constrains as the case study. By comparing the results, it is found that the EWCA has higher ability to find a feasible solution in a narrow searching space. The effectiveness of the improvements is confirmed.

KEYWORDS

Dynamic Adaptation, Multi-Reservoir Systems, Three Gorges Dam, Water Cycle Algorithm

INTRODUCTION

Due to continuous society improvement, the demands on energy supply increase constantly, which increases the gap in electricity power market. Moreover, because of enhancement of environmental protection consciousness, people prefer clean energy, which makes the energy issue more important. In such a case, the hydropower is considered as a promising energy that assuages the electricity shortage and satisfies the requirements of environmental protection. Namely, hydropower represents a cheap, clean, and renewable energy.

Furthermore, the construction of cascade reservoirs in river basin develops rapidly, which provides a substantial improvement of regulation and storage capacity of reservoir systems. Generally, the reservoir optimal operation refers to obtaining of maximal benefit from one or more objectives while meeting various physical and operation constraints.

DOI: 10.4018/IJSI.2019010102

The difficulty in cascaded-reservoir system optimization rises sharply with system complexity. Namely, a non-linearity caused by generating characteristic of hydropower units and a high-dimensionality of multiple reservoirs make the optimization process more difficult (Labadie, 2004; Yeh,1985; Wurbs,1994).

In order to find the optimal operation of multi-reservoir system, in the past decades, various optimization methods were proposed and applied. Nevertheless, an improvement in optimal operation that overcomes the shortcomings of reservoir systems was achieved. The linear programming was firstly applied by Hiew, Labadie and Scott (1989) to the eight-reservoir Colorado-Big Thompson (C-BT) project in northern Colorado. In addition, Trezos (1991) extended linear programming to binary, integer, and mixed-integer programming in order to deal with highly nonlinear, non-convex terms in the objective function and constraints.

Besides linear programming, a dynamic programming (DP) proposed by Bellman (1956) has been the most popular optimization method since it was applied by Young (1967) to a single-reservoir operational problem. Namely, DP can handle the nonlinearity and non-convexity easily, thus, it represents a powerful tool in reservoir operation optimization. Nevertheless, in multi-reservoir system optimization, "the curse of dimensionality" causes problems, and as the scale of problems increases, the computational and memory requirements grow rapidly, which further makes optimization scarcely possible to obtain. With the aim to deal with this problem, the improved algorithms based on DP, such as incremental dynamic programming (IDP) (Zhou, 2014), dynamic programming successive approximations (DPSA) (Larson, 1970), and discrete differential dynamic programming (DDDP) (Heidari, 1971), were proposed and their efficiency was proven by examples.

Due to development of operational theory and computer science technologies, an optimal operation of multi-reservoir system has been expanded to wider researching area.

Evolutionary and metaheuristic optimization algorithms, such as genetic algorithm (GA) (Proenca & Rodrigo, 1997), artificial neural networks (ANN) (Raman & Chandramouli, 1996), Ant Colony Optimization(Kumar & Reddy, 2006), Tabu Search (Mantawy & Hawary, 2002), differential evolution algorithm (Yuan et al, 2009), particle swarm optimization (Afshar, Kazemi, & Saadatpour, 2011; Afshar, 2012), imperialist competitive algorithm (ICA), and cuckoo optimization algorithm (COA) (Hosseini-Moghari, Morovati, Moghadas, & Araghinejad, 2015), were applied to the optimal operation of multi-reservoir systems with satisfactory results.

The water cycle algorithm (WCA) presented in this paper is a new metaheuristic algorithm introduced by Eskandar et al (2012). Nowadays, this algorithm is used to solve constrained engineering optimization problems. In the paper of Haddad, Moraej and Loáiciga (2015), it was shown that WCA has the ability of find the optimal solution and that it converges fast. Due to easy application and effective optimization abilities, WCA was successfully applied to many fields, such as operation optimization of reservoir systems, antenna array synthesis (Guney & Basbug,2015), weight optimization of truss structures (Eskandar, Sadollah, & Bahreininejad, 2013), etc. Since, WCA represents a new intelligent algorithm; many researchers study it in order to improve the computing performance (Sadollah, Eskandar, Bahreininejad, & Kim, 2015; Sadollah, Eskandar, & Kim, 2015; Luo, Wen, Qiao, & Zhou, 2016).

The paper is organized as follows. Firstly, the origin WCA and proposed WCA improvements are explained in detail. Then, the study area is described, and a monthly model of multi-reservoir system is presented. Meanwhile, the problem formulation and constraint processing are introduced; the enhanced WCA (EWCA) is applied to the multi-reservoir system model and EWCA efficiency is compared with efficacy of WCA and water cycle algorithm with evaporation rate (ER-WCA). Lastly, a brief conclusion is given.

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