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Review of hybrid evolutionary algorithms for optimizing a reservoir

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ABSTRACT

Many studies present hybrid algorithms to solve multiobjective uses of a reservoir. The reservoirs presented in this review are used for flood control, hydropower generation, ecological flow requirement and water distribution systems. While flood control and hydropower are main function of a reservoir, ecological flow requirement are shown to be an important part that should be incorporated into reservoir operation models. Evolutionary algorithms are shown to be capable of solving complex reservoir operation models with fast convergence rate. A review of different algorithms in solving different reservoir operation problems is presented. The results generated by these algorithms are effective, competitive, comparable and applicable. The algorithms present the solutions to the computationally expensive models in an efficient way. Systematic ways of solving different reservoir operation models are presented. Many models reviewed involve reservoirs operated in single objective, multiobjectives, single reservoir and multireservoir. Real time operation is shown to be superior to normal operation. The results generated by the evolutionary algorithms presented show that the algorithms are capable of solving complex and multidimensional problem of water resources. The non-dominated solutions generated are many and spread widely on the Pareto-optimal front.

Keywords: Reservoir operation; Flood control; Ecological flow; Water distribution; Evolutionary algorithm; Hybrid

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1. Introduction

Since the subject of reservoir operation has been studied, no algorithm is capable of satisfying all the requirements of a reservoir. Each algorithm has been able to perform to an extent resulting in the formulation of several algorithms (Hosseini-Moghari et al., 2015). The nonlinear and nonconvex of reservoir operation problems has made linear programming unsuitable for its solution. However, linear programming and dynamic programming have been used by some researchers who can adopt full stochastic approach. Multi-reservoir operation comes with a large number of decision variables especially when the operation is a long-term one. This has made linear programming and dynamic programming difficult to use. Yeh (1985) notes that 3 major models are usually used for multi-reservoir optimization which are linear programming (LP), non-linear programming (NLP) and dynamic programming (DP). Yeh (1985) gives full review of these models. According to the author, LP has been used widely for multi-reservoir operations as researchers normally find a way to linearise the problem. NLP is slow and is less suitable for reservoir operation because it cannot handle non-convex problems common to reservoir operations. However, some researchers still adapt NLP for reservoir operation problems. Nonlinearity and nonconvexity can be conveniently handled by DP making it widely used by researchers. DP also suffers setbacks in memory and exponential increase in computational requirements making it applicable to a system with few reservoirs. Other algorithms also seek to linearise the nonlinear water resources problems before solving them as linear problems. A mixed integer programming technique is used to model hydropower, water supply and other reservoir uses. However, hydropower, which is dependent on head and water flow which is presented as nonlinear, is linearized with two-dimensional function (Zhou et al., 2014). Consequently, more desirable algorithms are needed to model reservoir operation for efficient management (Gowda and Mayya, 2015).

2. Evolutionary algorithms

Evolutionary algorithms (EAs) offer alternatives to LP, NLP and DP. On the contrary, evolutionary algorithms (EAs) use constraint-handling methods to make them suitable to handle constraints in reservoir management and other water management problems. The most common constraint handling technique is penalty method. This method penalizes any solution that violates the constraints by making it infeasible. Most of the algorithms are comfortable with this constraint handling technique, as it is simple and efficient. There are many applications of EA to water resources management with success. Meanwhile, in a multi-objective optimization, it is not possible to find a single solution (as in single objective) that will optimize all the objectives simultaneously. However, we have a set of trade-offs between all the objectives known as Pareto optimal schemes. One objective cannot be improved without having a compromise on one or more of the other objectives (Adeyemo and Olofintoye, 2014).

Since the introduction of evolutionary algorithms, many applications to water resources have been successfully experimented (Ahmad et al., 2014). An algorithm called co-operative game theory for alternative framework for effective allocation was proposed by Madani and Hooshyar (2014). The algorithm provides fair and efficient utility shares of the beneficiaries. It was used to solve optimal reservoir operation for multi-objective and multi-reservoir system for fair and efficient water distribution. A hypothetical 3-agent three-reservoir system was used to test the model and results show that the algorithm can solve the problem efficiently. The objective of the model was to maximize the annual revenue of hydroelectricity generated from the reservoir, which was got from the monthly release. The constraints are the continuity equation, storage limits and release limits. Zhang et al. (2014) present a reservoir operation optimization with the objective of maximizing the benefit of water resource by finding an optimal solution to hydropower station within the operating period at the same time satisfying physical and operational constraints. The major objectives of the reservoir is hydropower and water supply which is similar to human demand objective (Chang et al., 2010). Evolutionary algorithms are efficient for reservoir operation; especially, in maximizing hydropower generation.

Multiobjective evolutionary algorithms are formulated based on the operation of evolutionary algorithms with some modifications; however, they are different from other multi-objective optimization techniques. Multi-objective evolutionary algorithms (MOEAs) are known to generate many non-dominated solutions in a single run unlike the classical techniques (Adeyemo and Olofintoye, 2014). MOEAs are also less sensitive to the continuity or shape of the Pareto surface. Several researchers have extended DE, an evolutionary algorithm, for solving multi-objective optimization. Abbass and Sarker (2002) presented Pareto differential evolution (PDE) algorithm. This algorithm has a wide application in many multi-objective optimization problems (Madavan, 2002). Pareto-based multi-objective differential evolution (PMODE) was proposed by Xue et al. (2003). Differential evolution multi-objective (DEMO) was demonstrated and suggested (Robic and Filipic, 2005). Also, adaptive differential evolutionary algorithm, ADEA, was presented and applied (Pan et al., 2009). In the same year, Multi-objective evolutionary algorithm, MDEA, was presented and applied in many water resources problems (Adeyemo and Otieno, 2010, 2009a, 2009b). More recently, combined Pareto multi-objective differential evolution, CPMDE, was proposed and applied to engineering problems (Adeyemo and Olofintoye, 2014; Enitan et al., 2014; Olofintoye et al., 2014, 2016).

Similarly, other multiobjective evolutionary algorithms are presented. Multi-objective cultured differential evolution (MOCDE) was presented to solve reservoir flood control problem (Qin et al., 2010). It was applied to three Gorges reservoir with success. MOCDE provides decision makers with many alternative non-dominated schemes with convergence to true Pareto optimal solutions and uniform coverage. It was suggested that MOCDE can also be useful in other water resources management problems. In the same vein, chaotic algorithm was combined with GA and DE which are population based search algorithms to solve hydropower maximization model of reservoir operation (Jothiprakash and Arunkumar, 2013). It was found that chaotic algorithm performed better than other algorithms tested. Also, flood control ability of a river-type reservoir was evaluated for discharge process and accurate simulation method for the flood storage by Zhang et al. (2017). The data was gathered from 394 river cross sections and digital elevation model data of the three Gorges reservoir area. The analysis showed that static capacity of the reservoir, dynamic flood control capacity and the maximum flood water