Cellular Automata Method for Hydropower Operation of Reservoirs

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Abstract

Optimal use of water from an available reservoir system is an important issue in water resources management. Many attempts have been made by researchers to achieve best possible performance of reservoir systems. Various optimization techniques have been used for optimal hydropower operation of reservoirs represented by a set of releases or storages. The main goal in hydropower operation of reservoir is maximizing energy production and as a result, maximizing net benefit.

In this study, an Adaptive Relaxed Cellular Automata (ARCA) method is developed for finding optimal hydropower operation policy of single reservoir system with maximum reliability. In the present method, constraints of the chance constrained optimization problem are classified as operational constraints and reliability constraint, and dealt differently. The proposed method applied for hydropower operation of Folsom reservoir located in State of California, and the results compared with those of Genetic Algorithm (GA). Results demonstrate the superiority of the proposed cellular automata method to GA.

Introduction

The theory of CA as a self-reproducing simulation model was first developed during the 1950s by Stan Ulam. Although CA was originally proposed as a simulation method to reproduce complex processes, but it is now being widely used to solve optimization problems of different engineering disciplines due to its interesting features such as simplicity and computational speed.

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The first application of the CA to water resources problem was proposed by Keedwell and Khu (2005). While most of researches used an ad-hoc transition rule based on engineering judgments and physical characteristics of the considered problem, Afshar and Shahidi (2009) were the first to propose a CA model with a mathematically derived transition rule and used it for optimal solution of reservoir operation problems.

Proposed Cellular Automata Method

Here, an adaptive relaxed cellular automata (ARCA) method is proposed for hydropower operation of reservoirs, with objectives of maximizing power generation and reliability. The mathematical forms of considered objective functions are as follow:

$$\text{Minimize } F_1 = \sum_{t=1}^{N} \left(1 - \frac{P_t}{ICAP}\right) \quad \text{and} \quad \text{Maximize } F_2 = \text{Reliaility}$$

Where P_t produced power at period t, ICAP is installed capacity of hydropower plant and *N* is the total number of operation periods.

Here, the cells are taken as discrete points in time representing the beginning and the end of each period of the operation. The cell states representing the decision variables of the optimization problem is, therefore, taken as the reservoir storage at these discrete points. The surrounding cells are considered as the neighborhood cells. The most important component of a CA model is transition/updating rule which the efficiency of the method is highly dependent on it. The updating rule for the proposed ARCA method is

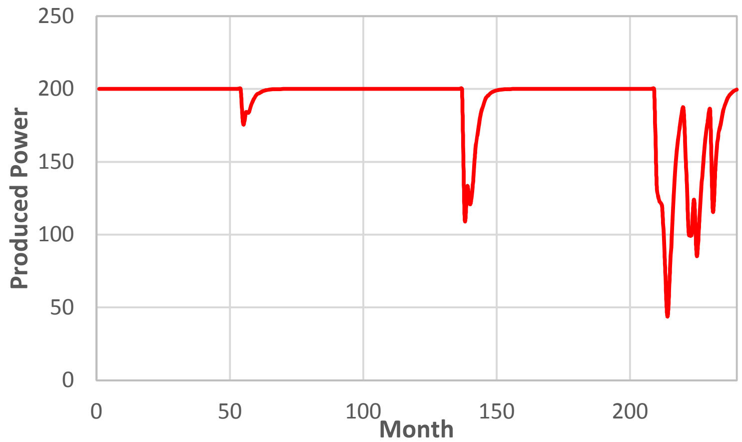
$$\Delta s_j = \frac{\frac{\partial P_{j-1}}{\partial S_j}\left(ICAP - P_{j-1}^{k}\right) + \frac{\partial P_j}{\partial S_j}\left(ICAP - P_j^{k}\right) + \alpha * \left\lfloor (CV_O)_j^2 + (CV_O)_{j-1}^2 \right\rfloor^k + \beta * \left\lfloor (\lambda_{j-1})(CV_R)_{j-1} + (\lambda_j)(CV_R)_j \right\rfloor^k}{\left(\frac{\partial P_{j-1}}{\partial S_j}\right)^2 + \left(\frac{\partial P_j}{\partial S_j}\right)^2 + (2 * B_O * \alpha) + \left(B_R * \beta * (\lambda_{j-1} + \lambda_j)\right)}$$

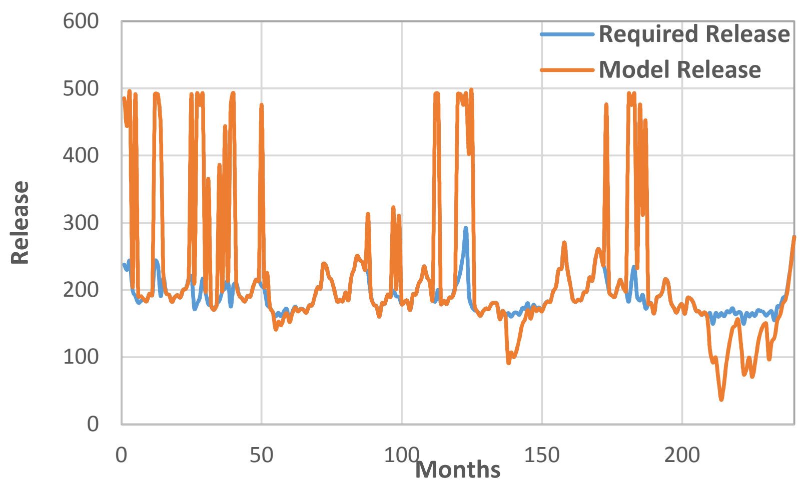
where B_O and B_R are binary variables with zero value if the solution at iteration *k* is feasible regarding operational and reliability constraints, respectively and with unit values otherwise. CV represents constraint violation.

The solution is started with randomly generated storage values and the updated storage values is then calculated using updating rule equation. The procedure is continued until the convergence criteria are met.

Model Application and Results

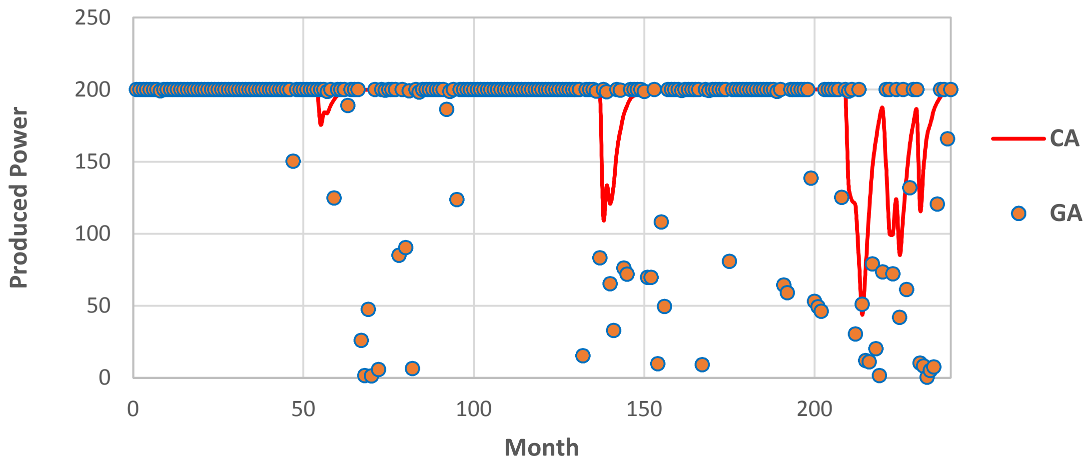
The proposed model applied to hydropower operation of Folsom reservoir in California. The installed capacity of power plant is considered as 200 MW with the efficiency of 85 percent. A twenty-year historical time series is used for monthly hydropower operation of the reservoir. The produced power during 240 months of operation is illustrated in the following figure.





The maximum reliability and the value of objective function F_1 obtained with the proposed method are 81.25 percent and 11.3 3, respectively.

To prove the efficiency and effectiveness of the proposed method, the same problem was also solved by a real coded Genetic Algorithm (GA). Here, the maximum reliability obtained by ARCA considered as target reliability for GA. It should be mentioned that GA could not achieve to the target reliability and the obtained reliability by GA was 78 percent with the value of objective function F_1 equal to 35.95. In other words, proposed ARCA method produced 12 percent energy more than that produced by GA method. Also it is interesting to note that the computational time for ARCA and GA were 4 and 2500 seconds, respectively.



Summary and Conclusion

An ARCA method was developed in this study for hydropower operation of reservoirs considering maximizing power generation and reliability, and applied to hydropower operation of Folsom reservoir In California. The results of the proposed method compared with those of GA and proved that the proposed method is efficient and effective for solving such problems.

Based on the results of this study and some previous researches, the cellular automata method is an efficient and powerful method for solving water resources management problems. However, the method is a new one and needs more researches to apply it to more practical problems.

References

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