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A Conditional Genetic Algorithm Model for Searching Optimal Reservoir Rule Curves

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Abstract: Rule curves are guidelines for long term reservoir operation. An efficient optimization technique is required to find the optimal rule curves that can mitigate water shortage in long-term operation. A Conditional Genetic Algorithms (CGAs) connected with simulation model was proposed to search the optimal rule curves of reservoir. The proposed model was applied to determine the optimal rule curves of the Lampao Reservoir (in the Northeast Region of Thailand). The results showed that the pattern of the obtained rule curves similar to both existing rule curve and the rule curves of traditional Genetic Algorithms (GAs). The CGAs model provided optimal solution faster than the traditional GAs model. Then all obtained rule curves were used to simulate the Lampao reservoir system with the 500 samples of synthetic inflow. Furthermore, these results of the obtained rule curves were compared to the obtained rule curves of simulation model and the traditional GAs. The results indicated that the situations of water shortage and excess release water of using the rule curves of CGAs are smaller than the situations of using the existing rule curves.

Key words: Rule curves, genetic algorithm, reservoir simulation, water shortage, flood plane, water resource management,

INTRODUCTION

Flood and water shortage are still serious problems in Southeast Asia specially Thailand. Integrated water resources management is an accepted method to solve these problems. There are 2 categories of integrated management including demand and supply management. These managements are addressed in the possible practice and high efficiency (Dooge, 2002). In the supply management, a reservoir simulation model is widely used to analyze the behavior of reservoir system on the computer. Rule curves of reservoir are fundamental guidelines for long term reservoir operation in order to minimize water shortage and flood plane in the future. Generally, rule curves are searched by reservoir simulation model and optimization techniques. In the past, the rule curves are obtained from reservoir simulation model by trial error process (Jain *et al*., 1998). This method is straightforward and applicable for both single multiple reservoirs. However, the reservoir simulation method does not guarantee to yield the optimal rule curves because of the experienced person who adjusted the rule curves.

Dynamic Programming (DP) is another optimization technique that applied to search the non-linear problems of water resource as well as to search the optimal rule curves (Bellman, 1957; Yakowitz, 1982; Esogbue, 1989). Unfortunately, the application of DP to multi-reservoir system is limited due to a dimension problem. To overcome this problem Chleeraktrakoon and Kangrang (2007) applied the DP with a Principle Progressive Optimality (DP-PPO) to determine the optimal rule curves of the multiple reservoir systems. However, this technique is complicated application.

Genetic Algorithms (GAs) is another search technique that applied to search optimal rule curves of the reservoir system (Chang *et al*., 2003, 2005; Chen, 2003). The best part of GAs model is that it can handle any type of objective function of the search. In addition, the applied GAs can handle any condition of reservoir simulation such as initial reservoir capacity and the period of inflow record. The GAs embedded the simulation model was applied to search the optimal rule curves for finding the suitable length of historic inflow record (Kangrang and Chaleeraktrakoon, 2008). The accepted objective functions are a shortage index, frequency of water shortage, average water shortage and magnitude of water deficit. However, the appropriate objective function for searching the curves is average water shortage. Also, a smoothing function constraint is required to include into the proposed GAs for fitting the rule curves (Kangrang and Chaleeraktrakoon, 2007). However, an alternative technique to reduce the fluctuation of rule curves in the output process is to limit the boundary of searching. To reduce searching boundary can activate the process to reach the optimal solution fast.

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This study thus proposed the genetic algorithm to connect with simulation model for searching the optimal rule curves of reservoir. A conditional constraint was applied to the search process for reducing the fluctuation of the obtained rule curves. A minimum average water shortage was adopted be the objective function of the search process. Comparison results of the Conditional Genetic Algorithms (CGAs) and the simulation model were presented to demonstrate the effectiveness of the proposed model at the end of the paper. The proposed model was applied to determine the optimal rule curves of the Lampao Reservoir (in the Northeast Region of Thailand).

MATERIALS AND METHODS

Reservoir simulation model: This study developed reservoir simulation model to describe the behavior of the reservoir system. This reservoir simulation model was constructed on the concept of HEC-3 (US Army Corps of Engineers, 1974) and it can be used to simulate the reservoir operation effectively. The reservoir operating policies are based on the reservoir rule curves and the principles of water balance concept. The reservoir system operated along the standard operating policy as expressed in Eq. 1:

$$R_{\upsilon,\tau} = \begin{cases} D_\tau + W_{\upsilon,\tau} - y_\tau, \text{ for } W_{\upsilon,\tau} \ge y_\tau + D_\tau \\ D_\tau, \text{ for } x_\tau \le W_{\upsilon,\tau} < y_\tau + D_\tau \\ D_\tau + W_{\upsilon,\tau} - x_\tau, \text{ for } x_\tau - D_\tau \le W_{\upsilon,\tau} < x_\tau \\ 0, \text{ otherwise.} \end{cases} \quad (1)$$

where, $R_{v,\tau}$ is the release discharges form the reservoir during year v and period τ (τ = 1 to 12, representing January to December), D_τ is the water requirement of month τ, x_τ is lower rule curve of month τ, y_τ is upper rule curve of month τ and $W_{v,\tau}$ is the available water calculated by simple water balance as described in Eq. 2:

$$W_{\upsilon,\tau+1} = S_{\upsilon,\tau} + Q_{\upsilon,\tau} - R_{\upsilon,\tau} - E_\tau - DS \quad (2)$$

where, $S_{\upsilon,\tau}$ is the stored water at the end of month τ, $Q_{\upsilon,\tau}$ is monthly reservoir inflow; E_τ is average value of evaporation loss and DS is the minimum reservoir storage capacity (the capacity of dead storage).

In the Eq. 1, if available water is in a range of the upper and lower rule level, then demands are satisfied in full. If available water over the top of the upper rules level, then the water is spilled from the reservoir to downstream river in order to maintain water level at upper rule level. If available water is below the lower rule level, release water is reduced. The policy usually reserves the available water ($W_{v,\tau}$) for reducing the risk of water shortage in the future, when $0 \le W_{\upsilon,\tau} < x_\tau - D_\tau$.

The release water of reservoir were used to calculate the situations of water shortage and excess release water such as the number of failure year, the number of excess release water, as well as the average annual shortage. These results will be then recorded for using in developed CGAs model.

Development of conditional genetic algorithms model: The developed CGAs to connect simulation model are described as follows. The GAs requires encoding schemes that transforms the decision variables into chromosome. Then, the genetic operations (reproduction, crossover and mutation) are performed. These genetic operations will generate new sets of chromosomes. The most common encoding schemes use binary strings (Jain *et al*., 1998). In this study, each decision variable represents a monthly level of the rule curves of reservoirs.

After the chromosomes (rule curves) of the initial population have been determined, the release water is calculated by the simulation model using these rule curves. Then, the release water is used to calculate the objective function for evaluating GAs fitness. Next, the reproduction including selection, crossover and mutation is performed for creating a new rule curve parameters in next generation. This procedure is repeated until the criterion is satisfied as shown in Fig. 1. There are 24 parameters (rule curve levels) for one reservoir which are represented by the chromosomes. This study used population size = 80, crossover probability = 0.9, mutation probability = 0.01 (Jain *et al*., 1998).

The objective function of searching the optimal rule curve is the minimum of average water shortage

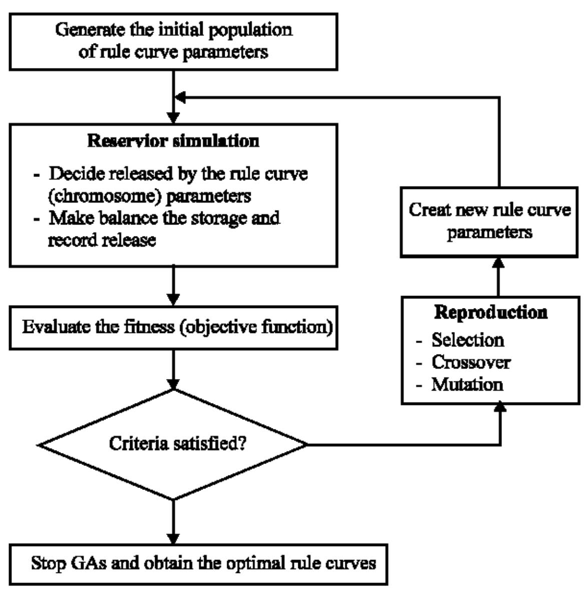

Fig. 1: Integration of CGAs and simulation model

(Aver--MCM/year) (Kangrang and Chaleeraktrakoon, 2007) obtaining from the simulation model which described as follows:

$$\text{Aver} = \frac{1}{n}\sum_{\upsilon=1}^{n} Sh_{\upsilon} \quad (3)$$

where, n is the total number of considered year. Sh_{υ} is water deficit during year υ.

To reduce the fluctuation of the obtained rule curves, the boundary of the search for each generation is limited. The range of searching for lower and upper rule curves is fixed base on the previous rule curves. These ranges cover the existing rule curves for the old reservoir that similar to pattern of existing rule curves. For the new reservoir, these ranges are inner the active storage for the new reservoir that dead storage for lower bound and normal high water level for upper bound. This method was applied to determine the optimal rule curves of the Lampao Reservoir, Kalasin Province (in the Northeast Region of Thailand). The monthly flow records, monthly water requirements from the reservoirs, their characteristic reservoir, monthly evaporation rate, percolation data and rainfall data were used in the study. This research project was conducted from Jan 2008 to Jan 2009.

ILLUSTRATIVE APPLICATION

The proposed CGAs model was applied to search the optimal rule curve of the Lampao Reservoir that located in the Chi River Basin (in the Northeast Region of Thailand).

Figure 2 shows the locations of the Lampao Reservoir. In the following, the obtained assessment results of the considered water-deficit and excess-release properties for existing (HEC-3), GAs and CGAs cases were presented. As shown in Fig. 3, the schematic diagram of flows within the total drainage basin of the Lampao reservoir system. The Lampao Reservoir has the capacity of 1,400 MCM (million cubic meters or 10^6 10^3). This reservoir is located on the Pao River. The verification needs monthly flow records and the other related data such as monthly water requirements supplied by the reservoirs, their characteristic curves and monthly evaporation rate. For the inflow record data, sequences of 23 year (1986-2008) monthly-flow records of reservoir were used. The locations of the flow gauging stations are shown in Fig. 2. The 500 samples of generated inflow were used to evaluate the proposed model. The stochastic inflows were generated by the MAR (1) (Chaleeraktrakoon, 1999). The other average hydrological data for each month included series of evaporation losses

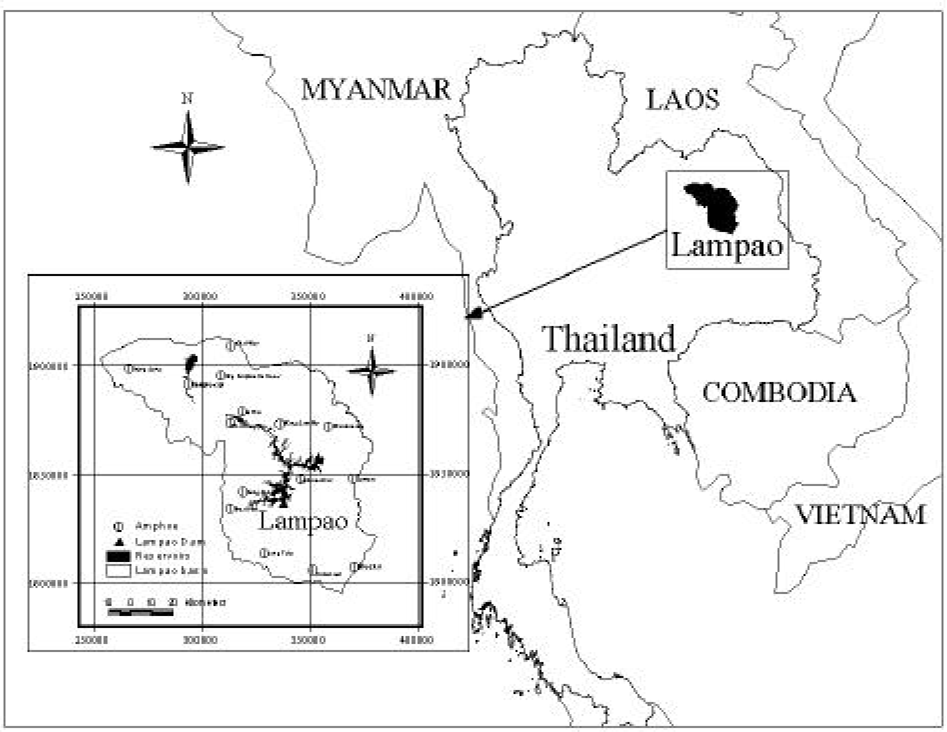

Fig. 2: Location of the Lampao reservoir

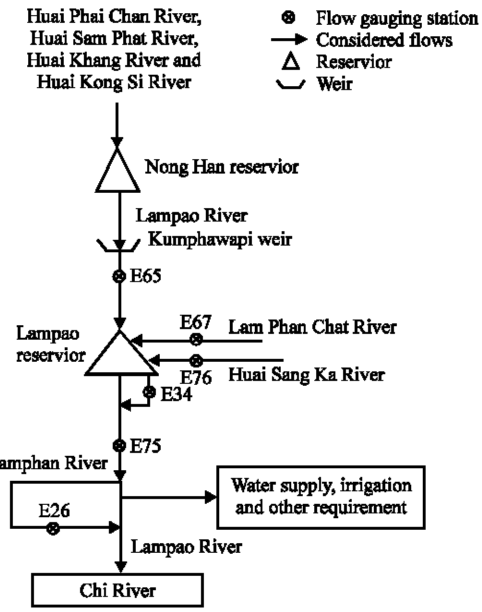

Fig. 3: Schematic diagram of flows in the Lampao River Basin (Other requirements consist of salinity, pollution control and navigation demands)

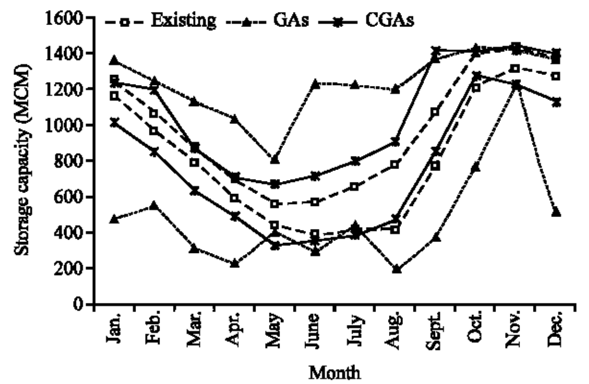

Fig. 4: Optimal rule curves of the Lampao reservoir

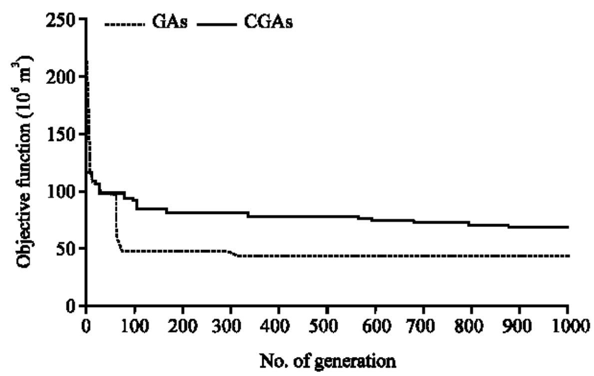

Fig. 5: Number of generation for searching optimal rule curves

and precipitation of the reservoirs were used for the simulation model. The considered water-requirement information of the studied basin was collected from the report of the Royal Irrigation Department of Thailand (RID).

RESULTS AND DISCUSSION

Figure 4 shows the optimal rule curves of CGAs compared with the rule curves of GAs and simulation model (HEC-3). The pattern of the new rule curves is similar to the existing curves of the simulation, but the obtained rule curves of GAs technique are fluctuate. However, the lower rule curves of both techniques during dry season (Jan-May) are the lower than theirs existing curves. Beside, the upper rule curves of using CGAs and GAs are higher than the existing curves. Then obtained rule curves were used to simulate the Lampao River Basin system. The monthly inflow were generated by SVD (MAR 1) (Chaleeraktrakoon, 1999) for evaluating water shortage and flood frequency. The results show the circumstances of water shortage and flood frequency (frequency of water shortage, average water shortage, the frequency of excess water and the average water release). The frequency of water shortage, the average water shortage and the maximum water shortage of rule curve from CGAs model are 0.443±0.083 time years^{-1}, 106±22 and 471±115 MCM year^{-1}, respectively. The flood frequency of excess water release, the average excess water release and the maximum excess release of rule curve's CGAs are 0.800±0.061 time years^{-1}, 698±27 and 2,593±280 MCM year^{-1}, respectively (Table 1). The results also indicated that most situations of shortage and excess release for CGAs model are smaller than the situations of HEC-3 such as maximum water shortage and average duration of water shortage.

Figure 5 shows the number of generation for searching optimal rule curves. The CGAs used 110 generations for reaching optimal rule curves, while the GAs model used 80 generations only.

The pattern of the new rule curves that using CGAs as shown in Fig. 4 is similar to the existing curves of the simulation because the boundary of searching is limited according to existing rule curves according to the incorporated smoothing function constraint to fit the rule curves (Kangrang and Chaleeraktrakoon, 2007). However, the pattern of the obtained rule curves using GAs technique is fluctuate due to widely boundary of searching (dead storage level to normal high water level). The fluctuation of obtained rule curves in this study

Table 1: Frequency, magnitude and duration of water shortage and excess release of the systems

			Frequency	Magnitude (MCM $year^{-1}$)		Duration (year)	
Situations	Rule curves	Parameters	Times $year^{-1}$	Average	Maximum	Average	Maximum
Water shortage	Existing	μ	0.926	327.2	669.9	13.0	16.4
		σ	0.049	20.6	85.6	6.3	4.8
	GAs	μ	0.348	51.7	409.4	2.4	3.6
		σ	0.088	19.6	148.1	0.8	1.3
	CGAs	μ	0.443	106.3	470.7	2.6	4.2
		σ	0.083	22.0	114.9	0.8	1.5
Excess release water	Existing	μ	0.979	922.6	2738.1	18.2	20.1
		σ	0.029	25.2	565.7	6.3	4.3
	GAs	μ	0.735	645.0	2525.6	3.7	7.4
		σ	0.062	26.7	554.4	1.3	2.5
	CGAs	μ	0.800	698.4	2593.0	4.5	8.7
		σ	0.061	27.3	579.9	1.7	3.0

μ: Mean, σ: SD

similar to the obtained rule curves in the previous study (Chang *et al*., 2003). The lower rule curves of GAs technique during dry season (Jan-May) and rainy season (Aug-Dec) are the lowest, this affected from the objective function of the search that try to sufficiently release water to meet the demand. In addition, the release condition in Eq. 1 directly controls remain water for next month in reservoir simulation.

Most situations of shortage and excess release of CGAs model are smaller than the situations of HEC-3 such as maximum water shortage and average duration of water shortage these because the obtained rule curves of CGAs are optimum solution, whereas the rule curves of HEC-3 are provided by trial error process (US Army Corps of Engineers, 1974; Jain *et al*., 1998). However, the situations of shortage and excess release of GAs model are the smallest because the wide boundary of searching provided the better solution. Although, GAs model provide the rule curves that get the least shortage and excess release situations, these rule curves can not use to practice because of theirs fluctuation.

For the number of iterations of each method, it indicates that the CGAs model and GAs model are not significantly different to get the optimal solution. Also, the run time of both models are used closely. According to the consideration of different inflow record length in GAs searching (Kangrang and Chaleeraktrakoon, 2008).

CONCLUSION

Rule curves are necessary guides for long term reservoir operation. The optimization techniques applied to search the optimal rule curves include simulation model, dynamic programming and genetic algorithm. This paper proposed a genetic algorithms connected simulation model to search the optimal rule curve. A minimum average water shortage was applied as the objective function of the search process. The limited bound of searching is used as the conditional constraint to reduce the fluctuation of the obtained rule curve. The developed CGAs model was applied to determine the optimal rule curves of the Lampao Reservoir (in the Northeast Region of Thailand). The results showed that the pattern of the obtained rule curves similar to the existing rule curve. The rule curves of traditional GAs model are fluctuate that can not use to practice. Then these obtained rule curves were used to simulate the reservoirs system by the synthetic inflow. The results indicated that the maximum water shortage and average duration of water shortage of CGAs model are smaller than the situations of HEC-3. The excess release's situations of the CGAs model are less than situations of HEC-3 for all properties. Although, GAs model get the rule curves that have the least shortage and excess release situations, these rule curves can not use to practice because of theirs fluctuation.

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