OPTIMIZATION OF MULTIPLE RESERVOIR RELEASES USING GENETIC ALGORITHMS: CASE STUDY OF MAE KLONG RIVER BASIN, THAILAND

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ABSTRACT

The main purpose of this research is to apply a Genetic Algorithm (GA) to the practical multiple reservoir release problem in which various water utilizations are considered. The investigation of developed GA technique, which is an optimization approach based on the mechanics of natural selection, derived from the theory of natural evolution, was carried out through application to the Mae Klong River Basin. The objective function is the maximization of release benefits, and the penalty functions are included if the downstream demands do not satisfied. A real world multiple reservoir release problem was solved satisfactorily using the GA approach. The results of the GA were compared with those of Electricity Generating Authority of Thailand (EGAT)'s simulation model. The GA derived operating curves bring the higher benefits, in terms of irrigation production and electricity production.

KEYWORDS

Genetic Algorithm, reservoir release, optimization, Mae Klong River Basin**.**

INTRODUCTION

Mathematical models are often used to make the decision. When they are used to select the best alternative out of a large number of possibilities, they are called optimization. This research introduces the new optimization technique to the multiple reservoir operation instead of using traditional simulation technique.

In recent years, Genetic Algorithms (GAs) have become popular among researchers as a robust and general optimization technique. The approach has been successfully applied to various fields of studies. The results of employment of GAs to a wide variety of problems have indicated their potential in the application to water resource management.

Genetic Algorithms (GAs) are optimization approach, which based upon the mechanics of natural selection, derived from the theory of natural evolution – hence the term evolutionary algorithms. GAs simulate mechanisms of population genetics

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and natural rules of survival in pursuit of ideas of adaptation (Goldberg, 1989 and Michalewicz, 1996).

GA is a powerful optimization approach, although as yet have seen limited application in water resources. In case of multiple reservoir release problem, the research by Wardlaw and Sharif (1999) expressed that GA approach is robust and easily applied to reservoir system operation problem. They evaluated GAs for optimal reservoir system operation using the Four-reservoir, deterministic, finite-horizon problem with a view to presenting fundamental guidelines for implementation of the approach to practical problems. Alternative representation, selection, crossover and mutation schemes were considered. Moreover, non-linear Four-reservoir problem and more complex Ten-reservoir problem were also applied. The results demonstrated that a GA could be satisfactorily used in real time operations with stochastically generated inflows and is capable of addressing large problems.

GAs approach has been applied to several topics related with water resource science. Wardlaw and Bhaktikul (2001) applied GAs to the water allocation problem using a simple test network and a more complex network on which the sensitivity of various GA approaches could be tested. The results of GA application to the relatively simple test systems were used in the Tukad Ayung irrigation system in Bali. The results demonstrated that the GA approach produced acceptable solution but offered no real advantage over the quadratic programming approach.

Wardlaw and Bhaktikul (2004) applied GA to two lateral canal scheduling problems. They are concerned with matching water demands from lateral canals with available supplies. In application to Hetao irrigation system, which is located at the Inner Mongolia region of China, the solutions obtained by GA were compared with those of 0-1 linear programming technique. The results indicated that GA produced greater water delivery and no constraint violations over the results produced by 0-1 linear programming formulation. The results produced by GA almost identical to those of integer programming technique. The main advantage over the integer programming approach is in execution time, the ability to deal with larger and more complex problems and its flexibility in application.

Because of the advantages of GA as an optimization approach on large and complex problems, and the successful of its application in many researches, the further study on the practical problem should be established.

RESEARCH OBJECTIVES

The main purpose of this research is to apply a GA to the practical multiple reservoir release problem in which many utilization of the multipurpose reservoir are considered. The specific objectives are as follows:

1) to apply a GA to the multiple reservoir operation in the study area;
2) to optimize the operating curves for reservoir system in the study area;
3) to evaluate GA performance against that of conventional approach in multiple reservoir release problem.

GENETIC ALGORITHMS

A Genetic Algorithm (GA) is an optimization approach based on the mechanics of natural selection, derived from the theory of natural evolution. GAs create a set of artificial chromosomes representing the value of variables, and reproduce a new generation by using bits and pieces of the fittest of the old and introducing new bits and pieces for better measure. They do this process time after time to find the string, which represents the optimal solution. (Goldberg, 1989 and Michalewicz, 1996)

A GA generally represents a solution using strings (or chromosomes) of variables that represent the problem (Figure 1). Each string comprises a number of blocks, which represent the individual decision variables of the problem (genes). The number of genes comprised the string depends on the decision variables of the objective function of the problem. The fitness of a chromosome as a candidate solution to a problem is an expression of the value of the objective function represented by it.

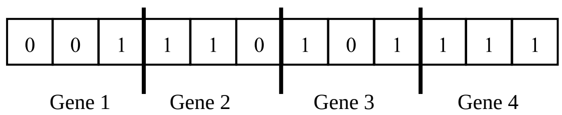

Figure 1. Sample of a chromosome comprises 4 genes, each gene has 3 bits

The population of chromosomes are processed and combined through a series of genetic operators according to their fitness to produce successive fitter chromosomes. The genetic operators used in the reproductive process are selection, crossover and mutation. Chromosomes in the population with high fitness values have high probability of being selected to next generations. Combination is achieved through the crossover of pieces of genetic material between selected chromosomes. Mutation allows for the random mutations of bits of information in individual genes. Through successive generations, fitness should progressively improve, and at the end of the evolution process, a chromosome representing an optimal solution should be obtained.

MAE KLONG RIVER BASIN

The investigation of developed GA technique has been carried out through application to the Mae Klong River Basin. Mae Klong River Basin is located in the western region of Thailand and has a boarder with Myanmar. The basin total area is about 30,800 square kilometers.

The Mae Klong River starts right at the spot where the Khwae Yai and the Khwae Noi River converge at Pakphrak, Kanchanaburi Province. Two rivers are in major tributaries of the Mae Klong River, originate from the mountain range forming the divide between Thailand and Myanmar. After the Khwae Noi and Khwae Yai River join up to form the main river, the Mae Klong River flows to the plain in the southeast before emptying into the sea at Muang Samut Songkhram District.

There are 3 reservoirs operated in the basin; Vajiralongkorn, Srinagarind and Tha Thung Na Reservoir. The reservoir system is operated for four main purposes, potable water supply, irrigation, salinity control and hydropower generation. Figure 2 illustrates the schematic of the Mae Klong River Basin.

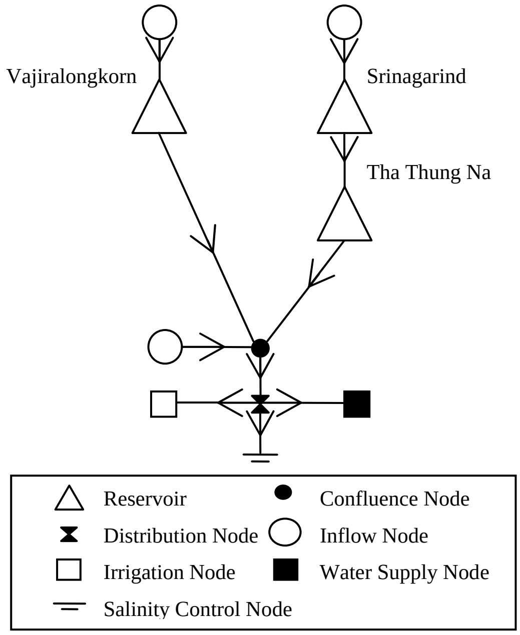

Figure 2. The schematic of Mae Klong River Basin

GENETIC ALGORITHM IN APPLICATION TO MAE KLONG CASE

1) The development of objective function and constraints

The complete objective function comprises the hydropower benefits and penalties for failing to supply the required water for irrigation and for salinity control. The function can be rewritten as follow:

$$\text{Maximize } Z = \sum_{i=1}^{n}\sum_{t=1}^{N} E_i(t)\, P_i(t) - \sum_{j=1}^{2} k_j P_j$$

where

n = number of reservoirs;

N = time step;

$E_i(t)$ = economic return from hydropower produced from reservoir i during time step t;

$P_i(t)$ = power generated from reservoir i during time step t;

k_j = penalty factor for P_j;

P_j = penalty for not meeting or over supply the irrigation (j=1) and salinity control (j=2) demand assumed to be of the following form:

$$P_j = \sum_{i=1}^{n}\sum_{t=1}^{N} [d_{j,i}(t) - x_{j,i}(t)]^2$$

$d_{j,i}(t)$ = demand j at the downstream of reservoir i during time step t;

$x_{j,i}(t)$ = supply j to the downstream of reservoir i during time step t.

The potable water demand was included in the objective function through the imposed constraints because it is the first priority to be fulfilled.

In addition, the constraints functions were also introduced. The storages and releases are limited by physical considerations. Reservoir storage should not exceed maximum allowable storage nor should it fall below a specified minimum level in any time period. Similarly, there are restrictions on the maximum possible release, and minimum turbine release is also may be required to avoid cavitations in any time step. Finally, the reservoir balance constraint was applied to the objective function also. Reservoir balance is the constraint set up to govern the transformation of multiple reservoir system from stage to stage. It is set up on the basis of mass balance and can be described by the following equation:

$$S_i(t+1) \quad = \quad S_i(t) + I_i(t) + M\,R_i(t) - E_i(t)$$

where
$S_i(t)$ = reservoir storages in reservoir i at time t;
$I_i(t)$ = reservoir inflows to reservoir i at time t;
$R_i(t)$ = reservoir releases from reservoir i at time t;
$E_i(t)$ = net reservoir evaporation from reservoir i at time t;
M = $n*n$ matrix of indices of reservoir connections.

2) The application of GA to Mae Klong River Basin and sensitivity analysis

There are several methods to set up GAs for each problem. In multiple reservoir release problem, Wardlaw and Sharif (1999) had already developed GA formulation and characteristics. They have provided a benchmark for practical optimization problems.

In the Mae Klong River Basin problem, which has three storage reservoirs in the system, consideration on time steps is given in monthly operating period. Thus there are 36 discrete variables to be represented in the GA.

The evaluation function used by GA corresponds to the objective function given in previous section. In addition, the constraints on storage are handled by using a penalty function based upon the degree of constraint violation. Figure 3 illustrates the plot of generation number versus maximum normalized fitness and average fitness of the population.

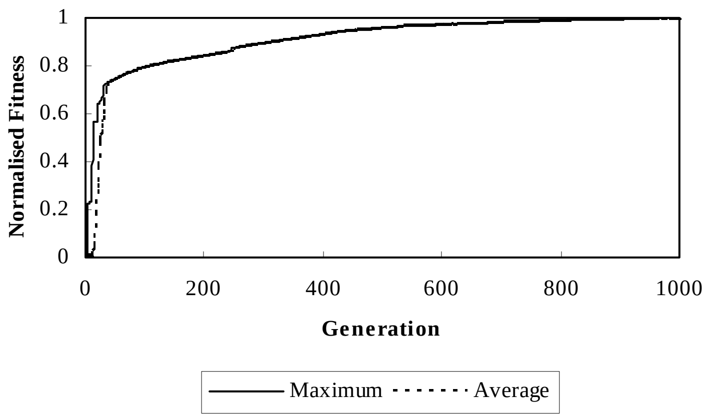

Figure 3. Generation versus maximum and average fitness

It can be observed from Figure 3 that the GA run begins with poor initial solutions but rises quickly. As the GA run progresses, the infeasible solutions are eliminated because the penalties assigned to them reduce their fitness, thus making their chances slim for selection process in the next generation. By the end of 300 generations, a number of good solutions have been found. Once the GA locates good solutions, some fine-tuning may be required to improve them. At the end of the run, a large number of feasible and near optimal solutions have been obtained.

In addition, sensitivity analysis has been carried out to evaluate the effect of crossover probability and mutation probability on the GA performance. A mutation probability of 0.139, which corresponds to 5 mutations per chromosome, was used to analyze the impact of crossover probability on the GA performance. All other parameters and run controls were set constant. GA runs were carried out with crossover probabilities ranging from 0.5 to 0.95. Sensitivity of the GA performance to crossover probability is presented in Figure 4. Fitness is expressed as the proportion of the maximum fitness produced by the GA run with the best crossover probability.

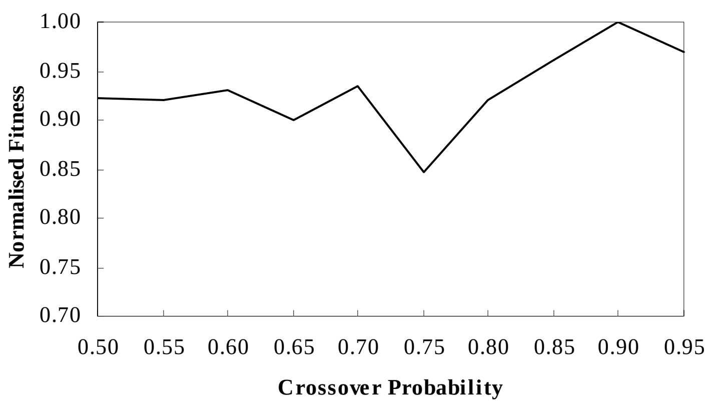

Figure 4. Sensitivity to crossover probability

The best values were achieved for the crossover probability of 0.9. It can be observed from Figure 4 that the performance of GA might not be good if too low values of crossover probabilities are used. The reasonable solutions were produced when the value of crossover probability had risen. The peak performance was achieved with a crossover probability of 0.9 but beyond this value, there is a little deterioration in performance again.

The impact of mutation probability on the performance of GA has also been analysed using a crossover probability of 0.9. The mutation probabilities are expressed in term of number of mutations per chromosome, which are varied from 1 mutation to 10 mutations per chromosome. Figure 5 shows the sensitivity of the achieved fitness to number of mutations per chromosome. Again, the fitness has been expressed as the proportion of the maximum fitness achieved by the GA run with the best mutation probability.

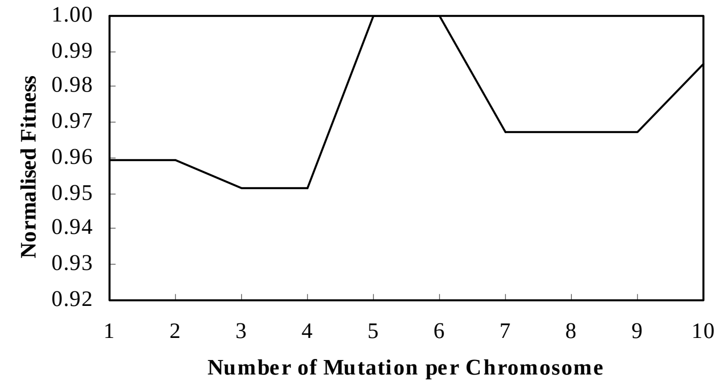

Figure 5. Sensitivity to mutation probability

Clearly, the best results were achieved with 5 and 6 mutations per chromosome. The value of 5 mutations per chromosome is preferable because it is lower. Since the chromosome for the Mae Klong River Basin problem was made up of 36 genes, the mutation probability corresponding to 5 mutations per chromosome is 0.139 (approximately 5/36).

Consideration has been given to the influence of population size on the performance of GA. The best parameters obtained from sensitivity test were used. The GA was run with different population sizes ranging from 60 to 200. The sensitivity of achieved maximum fitness to population size is shown in Figure 6.

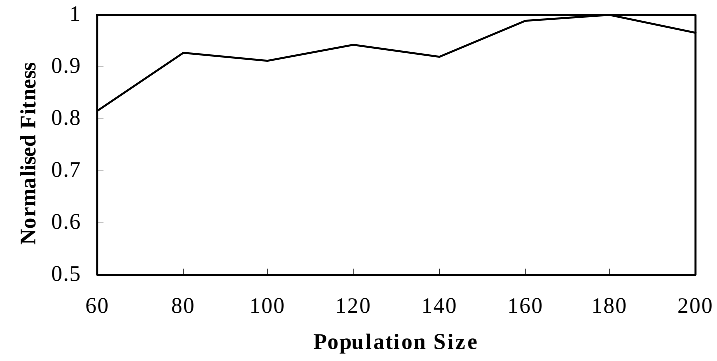

Figure 6. Sensitivity to population size

The acceptable results are produced with a population over 160. The best is 180. A decrease in population size decreases the total number of evaluations performed, and hence acceptable results may not be achieved with smaller population size. Furthermore, smaller population size cannot maintain diversity in the population. The choice of proper population size depends upon the judgment and experience of the user.

3) Comparison of the rule curves

Comparisons of the operating curves obtained from GA and from Electricity Generating Authority of Thailand (2001)'s simulation model are presented in Figure 7 and Figure 8. The GA results are based on the best parameter set resulting from sensitivity analysis. The Electricity Generating Authority of Thailand (EGAT)'s rule curve is the operating curve simulated by using inflows data and water requirements data in consistent with the upper rule curve and the lower rule curve. Both runs start at the same level. However, the rule curve of Tha Thung Na Reservoir to be compared with that of GA is not available.

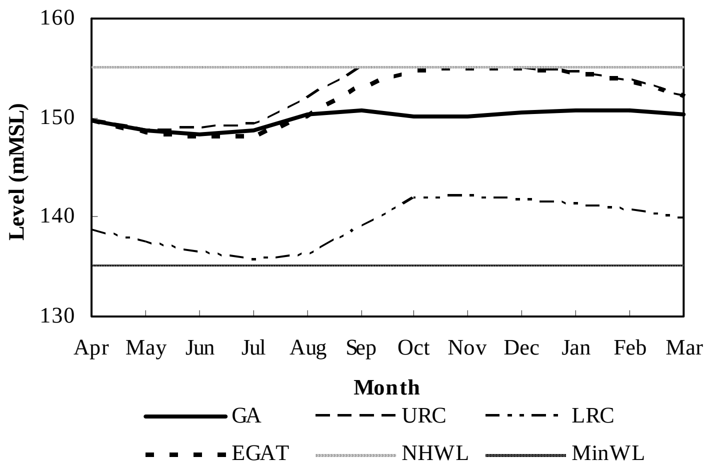

Figure 7. Comparison in Vajiralongkorn Reservoir

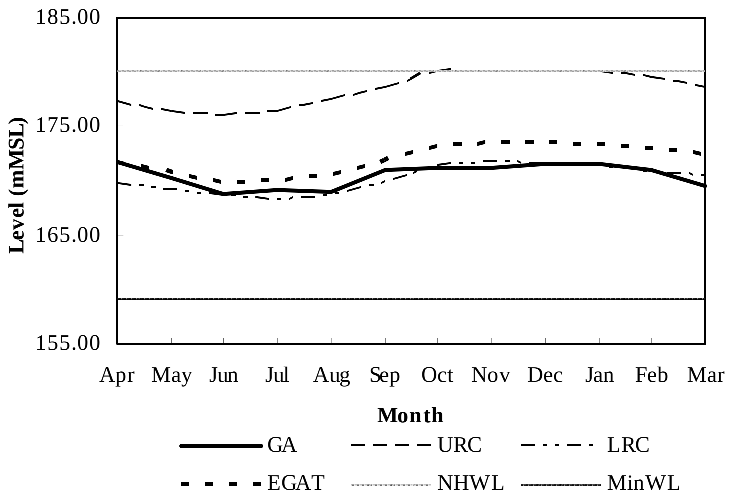

Figure 8. Comparison in Srinagarind Reservoir

It can be observed that GA operating curve for Vajiralongkorn Reservoir matches to the EGAT's operating curve for a few points only in the early period of the water year but not completely. Nevertheless, it can be observed that GA operating curve is drawn between the existing upper rule curve (URC) and lower rule curve (LRC) in every period of the water year. Also, it is drawn between the normal high water level (NHWL) and minimum water level (MinWL) of reservoir. This can be concluded that the existing rule curves completely cover the optimal ruling level, which is the level of the best utilization.

In case of Srinagarind Reservoir, the comparison of GA derived operating curve with the existing rule curve shows that GA derived operating curve does not match to the EGAT's operating curve except for a very first time step. It can be observed that GA operating curve matches to the lower rule curve for a few points but not completely. The GA ruling level in October, November, February and March are lower than the lower rule curve. This indicates that the operable space between the upper rule curve and the lower rule curve does not cover the best ruling level, and this means that the existing rule curves could not lead to the optimized reservoir operation

The response of the reservoir system to the operating curves produced by GA and the existing rule curves produced by EGAT's simulation model was also evaluated. The economics returns that could be realized from the basin for the operating curves produced by GA and those produced by EGAT's simulation model have been compared and are presented in Table 1.

Table 1. Summary of economic returns in million baht

	GA	EGAT
Irrigation Production	13323.06	11980.70
Potable Water Production	4898.88	4898.88
Energy Benefits	4255.11	3716.66
Total	22477.05	20596.24

Table 1 shows that the operating curves derived by GA produce significantly higher total returns than those obtained from the operating curves produced by EGAT's simulation model. Operation by using EGAT's rule curves returns lower benefits in case of energy benefits and irrigation production. The results thus demonstrate that the GAs can be efficiently used in identifying operation policies for multiple reservoir systems.

Summary and conclusion

The investigation of developed GA technique was carried out through application to a real multiple reservoir system in the Mae Klong River Basin. The revised rule curves resulted from the simulation model conducted by EGAT were used in the comparison with those from the optimization model using GAs.

A case study of Mae Klong River Basin problem was solved satisfactorily using the GA approach. The best parameter set obtained from sensitivity analysis had a crossover probability of 0.9, mutation probability of 0.139, which corresponds to 5 mutations per chromosome, for a population size over 160.

The results of the GA were compared with those of EGAT's simulation model. The GA derived operating curves bring the higher benefits, in terms of irrigation production and electricity production. GA operating curves also lead to the reduction of irrigation deficits, and salinity control deficits.

The comparison of operating curves produced by GA with those produced by EGAT's simulation model has been demonstrated that, in case of Srinagarind Reservoir, the space between upper rule curve and lower rule curve of EGAT does not cover the best ruling level, which can lead to the best utilization. The results suggested that the upper rule curve and the lower rule curve of Srinagarind Reservoir should be revised again in order to satisfy all demands as much as possible and to lead to the best utilization of water resources in the basin.

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