Derivation of a single reservoir operation rule curve using Genetic Algorithm

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Abstract: Genetic algorithms, founded upon the principle of evolution, are applicable to many optimization problems, especially popular for solving parameter optimization problems. Reservoir operating rule curves are the most common way for guiding and managing the reservoir operation. These rule curves traditionally are derived through intensive simulation techniques. In this paper to drive rule curve of a single storage system in Karkheh basin a genetic algorithm developed. In this model, the objective function is minimizing loss, considering the various inputs. Constraints that were in the reservoir, including constraints of reservoir continuity and constraints relating to volume, maximum and minimum operation and value of released. Decision variable is the amount needed to provide release **Derivation of a single reservoir operation rule curve using Genetic Algorithm.** *Life Sci J* 2012;9(4):1827-1830] (ISSN:1097-8135). http://www.lifesciencesite.com. 277

.Key-Words: optimization, rule curve, genetic algorithm, drought index

1 Introduction

Reservoirs can increase the reliability of the programs in promoting livelihood, raising agricultural productivity and reducing farmers' vulnerability to droughts. In order to overcome the problem of insufficient water supply during periods of low flow, attention has been drawn to improvement of water resources management, especially in optimization of reservoir operations (Chan and Cheng, 2005). Real time operation of River-Reservoir Systems (RRS) needs specific operational strategies. These strategies are practical guides for storage and/or releasing water in order to meet the human water demands, flood control and other objectives of reservoir operation management. Operational strategies can be either static or dynamic. Dynamic operational strategies are concerned with stochastic parameters of input current and variations of reservoir characteristics. One of the simplest reservoir operating strategies is "rule curve" which gives end-of-month values of reservoir storage volume (Karamouz & Kerachian, 2008). Genetic algorithm has been mostly used for solving hydro-engineering problems in supply network optimization, underground water resource management and extraction of reservoir operating rules. Esat & Hall (1994) employed a genetic algorithm to the linear four- reservoir problem ;the objective was to maximize the benefits of energy generation and irrigation under constant condition of storage and releasing water from the reservoir. Olivieira & Loucks (1997) used genetic algorithm to evaluate operating rules of multi-reservoir systems and showed that the genetic algorithm can be employed to specify operational strategies. The significant characteristic of the genetic algorithm, in this regard, is its freedom of action to specify, define and evaluate operating strategies. Tung *et al.* (2003) presented a specific kind of rule curve including optimal operational areas from a reservoir. They took the height of the point where the rule curve is broken as the decision variables of the problem. Using that, they submitted their rule curve which included optimal operational areas from a reservoir. Hormwichian *et al.* (2009) used a Simulation-Optimization model in order to design a rule curve for a single-reservoir system. To simulate the reservoir system, they used the equations governing HEC-3 Simulation model. They also used genetic algorithm in their system optimization. By presenting a special kind of genetic algorithm called "Constrained Genetic Algorithm", Chang *et al.* (2010) proposed an operational strategy for a multi-use reservoir. They presented a mathematical model explaining how to convert a constrained system to a non constrained one. This study proposes a constrained genetic algorithm (CGA) for water resources management that incorporates human needs and ecological sustainability requirements. The penalty function is established in a constrained genetic algorithm adopted to search for the feasible solutions of reservoir operations in different yearly hydrological events in order to achieve the demand in wet and dry seasons.

2 Problem Formulation

In order to determine optimal rule curve, one simulation-optimization model was used. With the assumption of the deterministic inflows, some relations are formed between regulated outputs and other parameters and variables. These relations were incorporated into continuous equations and other operational criteria. Furthermore, they were added as constraints to the optimization model. Using the

Shiang Shi Weriol (1994) criterion, index ID (K) was employed for determining the relative conditions of wet and dry year's conditions. Based on above criterion, annual inflows into the reservoir were ranked from 1 to 5 using index ID (K) (K=1,2,..5), in terms of the relative wet or dry year conditions. Using this ranking, the model is capable of determining different year conditions (five ranks of dryness or wetness).

2.1 Drought index

The Shiang Shen Weriol criterion was used for determining the relative drought conditions. If $\mathbf{I_m}$ is long-term annual flow average and I is annually flow average and s denotes the standard deviation of long-term annual discharge, we have:

$$\frac{I-I_m}{S} < -1 \qquad \textit{very dry}$$
$$-1 < \frac{I-I_m}{S} < -0.5 \qquad \textit{dry}$$
$$-0.5 < \frac{I-I_m}{S} < 0.5 \qquad \textit{normal} \qquad (1)$$
$$0.5 < \frac{I-I_m}{S} < 1 \qquad \textit{wet}$$
$$1 < \frac{I-I_m}{S} \qquad \textit{verywet}$$

2.2 Objective function

As it was mentioned before, submitting a scant deficit in the current time period for decreasing the intensity of a dramatic deficit could be economical. Obviously, despite operational restrictions, the minimum and maximum regulated flows should be within a range which its fluctuation could be tolerated by consumers. Increasing the range of regulated flows is equal to decreasing its fitness. Therefore, a definite relationship between regulation flow values and imposed deficits and excesses was established and model objective function has been defined in form of maximization of regulation flow values. So, a penalty function is defined in terms of deficit or excess. Therefore, we have,

$$Max\ UF = 1 - k_1.Def^2 - k_2.Exc^2$$
$$Def = Max\left\{0, \left[\sum_{d=1}^{Nd}\sum_{t=1}^{NT}(dem(d,ID,t) - \sum_{t=1}^{NT}O(t,Y)\right]\right\} \qquad (2)$$
$$Exc = Max\left\{0, \left[\sum_{t=1}^{NT}O(t,Y) - \sum_{d=1}^{Nd}\sum_{t=1}^{NT}(dem(d,ID,t)\right]\right\}$$

Where UF is the degree of system fitness and k_1 و k_2 are constants. With the increase of sensitivity, the operators of k_1 و k_2 increase and fitness of the regulated flows of smaller and bigger values than the demand decreases. Appropriate selection of k_1 و k_2 coefficients depends not only on performance functions and plant sensitivity to water deficit tensions, but also the management of transmission, distribution of water and even social tensions. It should be noted that these coefficients are representative of overall condition of desired sites. It is clear that along with the increase of above-mentioned coefficients, the system flexibility will be diminished too; Defis the deficit amount in a year and "dem(d, ID, t)" is the required deficit amount of "d" in the time period of "t" according to ID^{th} element of wetness-dryness conditions; "O(t,Y)" is reservoir output in the time step of "t" in the Yth year and "Exc" equals to the sum of annual excess regulation flow.

2.3 Constraints

The Continuous constraints and system capacity

$$V(t,Y) = V(t-1,Y) + I(t,Y) - O(t,Y) - L(t,Y) \qquad (3)$$
$$t = 1...Nt, Y = 1...NY$$
$$L(t,Y) = \left[a_0 + a\frac{V(t-1,Y)+V(t,Y)}{2}\right].e(t) \qquad (4)$$
$$V(t,Y) < V_{MAX} \qquad (5)$$
$$V(t,Y) > V_{MIN} \qquad (6)$$
$$V(Nt,NY) = V(0,0) \qquad (7)$$
$$V(t,Y) \geq 0 \qquad (8)$$
$$O(t,Y) \geq 0 \qquad (9)$$
$$L(t,Y) \geq 0 \qquad (10)$$

V(t,Y)= reservoir storage volume in the time step t in the year Y, I(t,Y)= inflow to the reservoir in the time step t in the year Y, O(t,Y)= outflow to the reservoir in the time step t in the year Y, L(t,Y)= reservoir losses in the time step t in the year Y, e(t)= vaporization height in the time step t, a_0 : y-intercept of the characteristic curve of reservoir, a: slope of the characteristic curve of reservoir.

$$O(t,Y) = b_0(ID(k),t) + b_1(ID(k),t)V(t-1,Y) \qquad (11)$$
$$t = 1...Nt, Y = 1...NY$$

b_0 = y-intercept of reservoir rule curve, b_1 **= slope** of reservoir rule curve

2.4 Architecture of simulation-optimization model

The reservoir operation model used in this study includes sub-sections of simulation and optimization model. The optimizer of this system includes a constrained genetic algorithm. First, generations of model decision variables that are b_0 , b_1 are defined randomly and inserted into sub-section of simulation as the inputs and in this level, using system cohesion relations and steering technical examination, and other model parameters including regulation currents and excess amount are determined and evaluated. In the next step, the evaluated chromosomes are inserted into genetic algorithm sub-section for accomplishment of crossover, mutation and reproduction operations. The modified generation is delivered again to simulation sub-section; this process is repeated until the system convergence is reached. In Fig.1 the function of simulation-optimization model is presented.

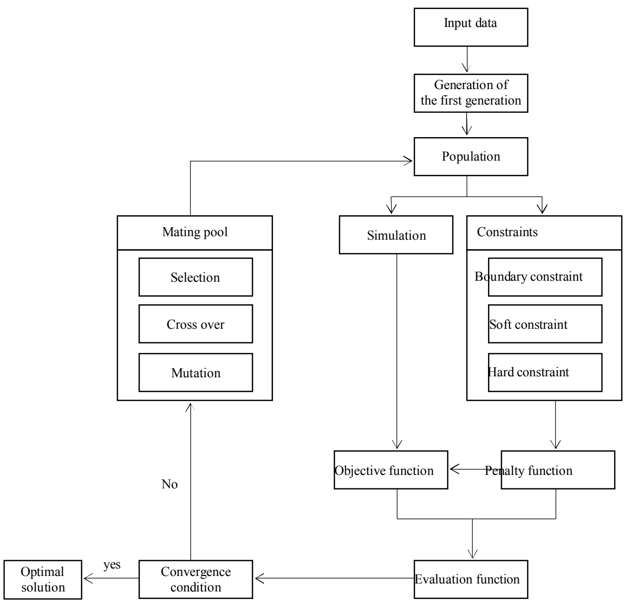

Fig 1. Architecture of Simulation-Optimization model

2.5 Penalty functions

These functions are defined in the way that equilibrates between keeping some infeasible solutions and rejecting some of infeasible solutions. In order to accomplish this task, penalty functions are defined as follows:

$$G(1) = -C(1).O(t,Y) \qquad IF \quad O(t,Y) < 0 \tag{12}$$

$$G(2) = (V(t,Y) - V_{MAX}).C(2) \qquad IF \quad V(t,Y) > V_{MAX} \tag{13}$$

$$G(3) = (V_{MIN} - V(t,Y)).C(3) \qquad IF \quad V(t,Y) < V_{MIN} \tag{14}$$

$$G(4) = \left|V(Nt,NY) - V(0,0)\right|.C(4) \qquad IF \quad V(Nt,NY) \neq V(0,0) \tag{15}$$

where G(1) denotes the penalty function of negative releasing; C(1) is a constant; G(2) is the penalty function of storage more than maximum storage volume; C(2) is a constant; G(3) is penalty function of storage lesser than minimal reservoir volume; C(3) is a constant; G(4) denotes penalty function for destabilizing the reservoir balance during the planning period and C(4) is a constant.

2.6 The fitness function

For completing the constrained genetic algorithm, model constraints should be mixed with Objective function (UF) to the fitness function guides the searching procedure the optimum solution by imposing appropriate penalties of $P(\vec{S})$ Fitness function equation is defined as

$$F(\vec{S}) = f(\vec{S}).P(\vec{S})$$

$$P(\vec{S}) = 1 + \sum_{j=1}^{nc} G_j(\vec{S}) \qquad j = 1 \ldots nc \tag{16}$$

Where $\vec{S}$ is the decision variable vector; $F(\vec{S})$ is fitness function; $f(\vec{S})$ denotes objective function, and nc is constraints number of the model.

2.7 Convergence conditions

For controlling the convergence conditions of algorithm, two criterions have been used: fitness re crossover rate one and maximum generation numbers one. Fitness recrossover rate is a generation fitness growth average in comparison with that of old generation and maximum generation number is repetition number of processes related to generation recrossover and reproduction.

3 Problem Solution

The Karkheh dam was studied. Karkheh reservoir dam (earth fill with clay core) is constructed on the Karkheh River. This river is the Iran's third biggest river considering water yield and it is regarded as a wild river with flooding regime. This river with 900 KM length, originates in the central and south western zones of Zagros Mountain range and extending from north to south flows into Hoor-al-azim lagoon and Hoor-al-hoveizeh in the south western regions of Khuzestan province. Among the main objectives of Karkheh reservoir dam is controlling 70 percent of Karkheh river surface runoff for the following proposes: Irrigation of about 220000 hectares (544000 acres) of the lands of downstream plains, which are placed on Pay-e-Pol (Avan, Dosaleq, Arayez, and Baqeh), and also Hamidi-yeh, Ghods, Dasht-e Azadegan, Dasht-e –Abbas plains which are located in the north-west and the west of Khuzestan province. Protecting about 80000 hectares of the downstream lands against the danger of destructive floods. Water diversion of the dam through the construction of the Dasht-e-Abbas pressure tunnel.

The average of released flow of different seasons for wet and dry years is shown in Fig. 3. According to this Figure, in all the periods, the highest released is occurred in summer and the lowest released is occurred in Fall. Considering the time model of plantation and the major demand of agriculture compared to other demands, this process seems logical. b $_1$, b_0 values are shown in Fig. 4.

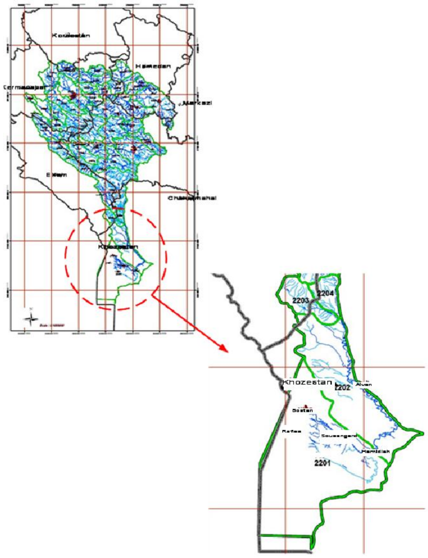

Fig. 2 Location of Karkheh reservoir system

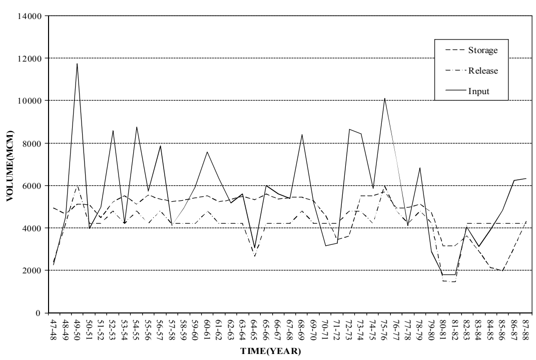

Fig. 3 The chart of input, storage and released flows of performing the program

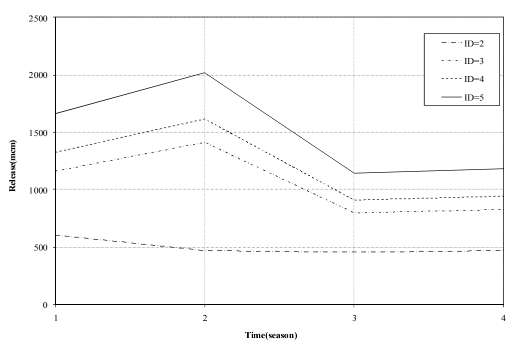

Fig. 4 The average reservoir released flow in different periods

4 Conclusion

In this paper to drive rule curve of a single storage system in Karkheh basin a genetic algorithm developed. In this model, the objective function is minimizing loss, considering the various inputs. Constraints that were in the reservoir, including constraints of reservoir continuity and constraints relating to volume, maximum and minimum operation and value of released. Decision variable is the amount needed to provide release. Results showed that 15% mutation rate with population of 100 chromosome, genetic algorithm has the best performance. The results of application of the model in total simulation period shows that, the maximum lack equivalent to 4.2% of the total simulation period and maximum surplus is equivalent to 2.2% of the total simulation period.

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10/6/2012