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Multi Objective Operation Optimization of Reservoirs Using Genetic Algorithm (Case Study: Ostoor and Pirtaghi Reservoirs in Ghezel Ozan Watershed)

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Abstract. In this study, a Genetic Algorithm model for optimal operation of a multi-reservoir and multi-objective water resource system in Ghezel Ozan watershed for hydropower generation and flood control is developed. The system is made of two reservoirs in series on the Ghezel Ozan's river. This model is used for optimal reservoir operation, allocation of water among different power plants and keeping a part of storage volume to control the probable floods using a definite combination of decision variables (Release of water to the power plants). The model operation for 12 months of a year shows that, the amount of releases in flooding months of the year is more than others.

Keywords: Multi-Objective Optimization, Multi-reservoir Systems, Genetic Algorithm, Pareto Front.

1. Introduction

A reservoir system has been a wide variety of purposes which some of them are not in line with each other. By using mathematical modeling, the behavior of systems can be defined in mathematical terms, and they will be examined under different conditions. In general, since, the optimization model of operation of a multi-reservoir system is a non-convex, nonlinear programming problem (NLP) which its purpose is to maximize the production of hydroelectric power and to maximum volume control flood reservoir, Evolutionary search methods such as genetic algorithms (GA) can be used to resolve such issues. [1], [2] In this study, a Model of Genetic Algorithm has envisioned to optimize operation of a two-reservoir system and two-objective Water Resources in order to produce hydroelectric power and controlling of probable floods. To develop the model, it is necessary the decision variables are presented in the form of chromosomal genes in the first step. Functions also are selected as a proper indicator for fitting of chromosomes and constraints governing the issue to be determined associated with Penalty functions. The next step is to obtain the most appropriate model for the optimal operation of reservoirs and allocate it to hydroelectric powerhouses due to the specific values of the state variables.

The purpose of this study is to develop a water resource planning model for optimal operation of a multi-purpose multi-reservoir system and water allocation for energy production, especially in the flood months of the year which the reservoir should be kept empty as far as possible.

2. Materials and Methods

2.1. Case Study

Watershed area of Ghezel Ozan has been between east longitude 46 °-27' to 51°-6' and north latitude 35° to 37°-56'. The area is supposed to study in this research is Between Ostoor Dam to downstream of Pirtaghi dam. The optimization problem is presented schematically in Figure 1. The above model has been done for a period of one year (twelve months) which has started in September and will finish in October.

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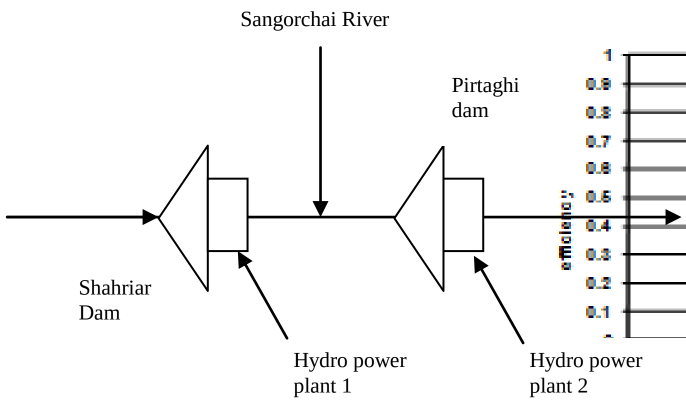

Fig. 1 : Schematic form of optimization problem

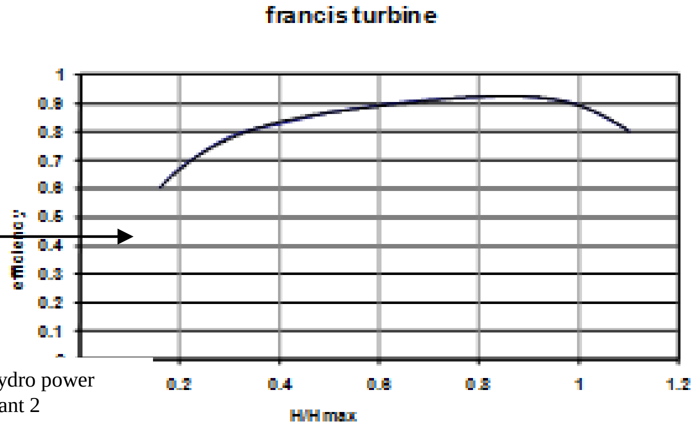

Fig. 2 : shows the changes in the efficiency of Francis turbine against the ratio of maximum head to head

2.2. The general structure of the model

2.2.1. **Objective functions:** The proposed optimization model has two objective functions that are as follows: [3]

$$f_1 = \max imize \sum_{i=1}^{n} \sum_{t=1}^{T} pwp^t \times PE^t \tag{1}$$

$$f_2 = \max imize \sum_{i=1}^{n} \sum_{t=1}^{T} c^t \times (S_i^n - S_i^t) \tag{2}$$

Which : n : Number of reservoirs for case study , T: Time horizon for operation model (12 months) , pwp^t : The Price of a unit of energy produced per month t by Rials on Megawatt hour , PE^t : The energy produced in the reservoir i and month t by watt which is obtained from the following equation:

$$PE_i^t = \eta_i^t \times \gamma \times R_i^t \times H_i^t \times PF_i \times d_i \times 24 \tag{3}$$

In Which: η_i^t is Turbine Efficiency in the powerhouse of the reservoir i in month t which is a function of ratio of head to maximum head, γ is a specific weight of water which is equal to 9806 (N/m3) , R_i^t :The amount of releasing water into the powerhouse in order to produce energy from reservoir i in month t according to cubic meters per second , H_i^t :Head Water Purification over the turbine according to Metegross headis equal to gross head minus the head loss , PF_i : Power plant factor of reservoir i , d_i : Number of days in each month of the year , c^t : Flood constant factor which is equal 1 in flood month and is zero in other months, S_i^n : Volume reservoir in normal level in reservoir i according per cubic meter and, S_i^t : Volume reservoir i in mount t according per cube meter .In the above equations, the only unknown variable is the rate of releasing of water to the powerhouse in order to produce energy and other variables are measurable and or can be calculated.

2.2.2. **Model constraints:** Water balance in reservoirs

$$S1_i^{t+1} = S1_i^t + I1_i^t + P1_i^t - E1_i^t - R1_i^t - Spill1 \tag{4}$$

$$S2_i^{t+1} = S2_i^t + I2_i^t + I3_i^t + P2_i^t - E2_i^t - R2_i^t - Spill2 \tag{5}$$

The number 1 represents the Ostoor Dam and the number 2 represents the Dam Pirtaghi and the number 3 represents Sangchai river. S_i^t and S_i^{t+1} are volume of water stored in the reservoir (m^3) at first and last of period t in reservoirs 1 and 2, respectively. I_i^t :River discharge inlet to reservoir i in month t , P_i^t : The rate of precipitation in area of reservoir i in month t , E_i^t :The rate of evaporation of area of reservoir I in month t , R_i^t : The rate of water output from the powerhouse from reservoir I in month t and , $Spill_i^t$: The rates of water overflow overflow from . Reservoir i in month t. [4]

The reservoir water volume is limited to maximum reservoir volume per period:

$$S_t \le S_{\max} \tag{6}$$

Limitation of the amount of released water: The rate of input water in a powerhouse will increase by head changes between the powerhouse operation level to a normal level reservoir.

$$R1 \le R1_{\max} \tag{7}$$

$$R2 \le R2_{\max} \tag{8}$$

Where $R_{\max}$ is the Maximum reservoir release from reservoir to powerhouse. To calculate $R_{\max}$ discharge relationship in intakes is used:

$$R = C_d .A.\sqrt{2g.H_{\max}} \tag{9}$$

Where C_d is the flow coefficient which is equal to 0.6, A is the cross section area of penestak and H is Heads Water Purification over the turbine. A minimum flow in downstream to protect environmental issues: To protect the environment, it requires a minimum flow in the river. This constraint is defined as follows:

$$R1 + Spill1 \ge MDT1 \tag{10}$$

$$R2 + Spill2 \ge MDT2 \tag{11}$$

Where $MDT1$ and MDT2 are the minimum demand for water in downstream reservoirs 1 and 2 in terms of cubic meters, respectively. These amounts are equal to the maximum amount of monthly discharge in the month which statistically is the lowest mean discharge during 43 years and they are 42.85 and 66.85 million cubic meters for reservoir 1 and 2, respectively.

Penalty functions: Penalty function related to the water volume of reservoir [5]:

$$if \quad S_t \prec S_{dead} \quad P_S = \sum_{i=1}^{T} (1 + K_t [S_t - S_{dead}]^2) \tag{12}$$

Penalty function related to the rate of releasing water

$$if \quad R_t \prec R_{\min} \quad P_R = \sum_{i=1}^{T} (1 + K_t [R_t - R_{\min}]^2) \tag{13}$$

Penalty functions related to the minimum required downstream:

$$if \quad [R_t + Spillway_t \prec MDT] \quad P_{MDT} = \sum_{i=1}^{T} (1 + K_t [R_t + Spillway_t - MDT]^2) \tag{14}$$

3. Results and Conclusion

Number of chromosomes considered for this study is equal to 300. The fitness rate of each chromosome can be obtained by getting the objective function values. This process is repeated for all chromosomes in each generation. Roulette wheel’s method is used for selecting parent chromosomes for the next generation. The next step is cutting process to produce the next generation. The process of cutting is done Due to the possibility of cutting [6]. In this study, the possibility of cutting is considered equal to $P_{crossover} = 0.7$ with trial-and-error [5]. In this case, for each chromosome is considered random number between zero and one. If the random number is smaller than the probability of cutting, some genes are selected randomly for each chromosome, and they are replaced with chromosomal genes are located in the vicinity of them. The last step in the production of the new generation is mutations in chromosomes. The process of mutation is performed According to the probability of mutation. Therefore, for each gene is considered some probability. In the present study, Mutation probability has been selected $P_{mutation} = 0.006$ with trial-and-error [5].

Based on the advanced computer program, deterministic model of genetic algorithms is written in the Matlab programming environment.

Figure 3 shows how this convergence towards the optimal solution in 500 generations of repeated by genetic algorithm model. Figure (a) is related to the optimal value of the first objective function at each repetition, which is equal to income obtained from the sale of electricity generated at the powerhouse that is being studied and according to it; the chart takes steady state from 200 generations. Figure (b) is related to the optimal value of the second objective function at each repetition, which is equal to the total stored volume in two reservoirs that are being studied during Flooded 4 months for flood control and prevent the probable risk because of it in downstream and according to it, the generation of approximately 200, the chart takes steady state. Since the objective functions are in conflict, so, increasing amount of one function decreases other the function value and vice versa. In this case, The Pareto front is formed. Figure 4 shows The Pareto front of the issue or in other words, the set of answers related to the issue. Total penalty functions are zero in each Pareto optimal response which indicates that the constraints are satisfied. Curves in the figure 4 are because the aim of the model is to maximize both functions, so with increasing an objective function, another objective function is reduced. According to Figure 5, water height in reservoirs 1 and 2 are lower in wet months from February to April comparing with other months of the year. The reason is that because the sole purpose is maximizing energy production and revenue from the sale of it in eight non-wet months of the year, the model goes to maximize water level and volume of the reservoir in these months, but in wet months, in addition to the above purpose, the other purpose is added to the model which is to maximize store volume to control flood, thus height water in the reservoir becomes low, so that both the objective functions will be optimized.

Amount of releasing water to the powerhouse in the reservoir 2 is more than reservoir 1. One of the main reasons for this issue is that this reservoir is bigger than reservoir 1 and its powerhouse. The release rate in wet months is maximum because of optimizing the second objective function of the problem, the model tries to keep empty the reservoir in order to control the flood through increasing the rate of releasing.

If you plot on a graph over time changes of any installation capacity and energy production in each powerhouse, Figures 6 and 7 will be achieved. The installed capacity of the hydro power plant depends on a number of hydraulic parameters. The following equation is used for calculation of installation capacity in the power house:

$$I.C = \frac{\eta.\gamma.Q.H}{10^6} \tag{15}$$

The IC is the installation capacity of powerhouse which is based on MW, and Q is discharge is released from the powerhouse through its intakes, after calculating installation capacity, it is possible to obtain monthly energy production powerhouse by using the following equation:

$$E = I.C \times PF \times 24 \times t \tag{16}$$

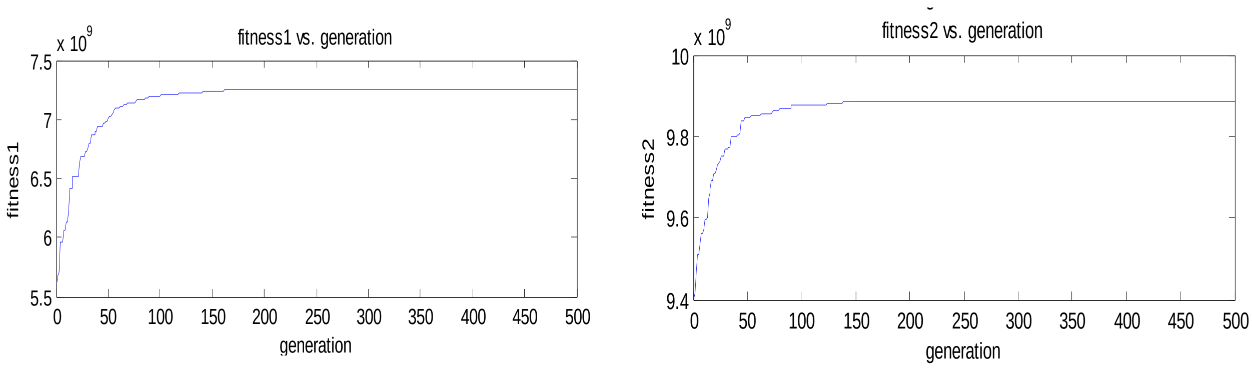

Fig. (3a), (3b): Convergence optimal answer in objective function, (fitness1& fitness2)

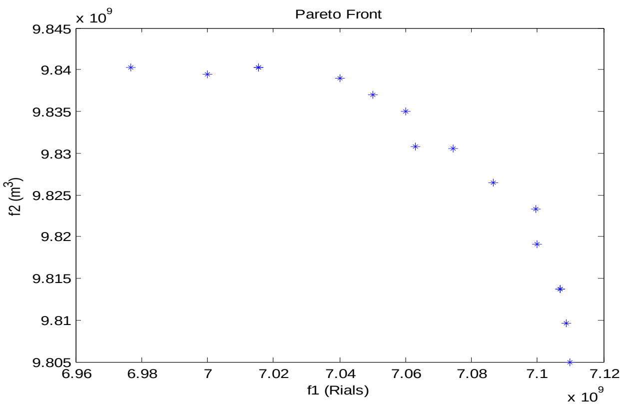

Fig. 4: Pareto front in optimal state (optimal answer)

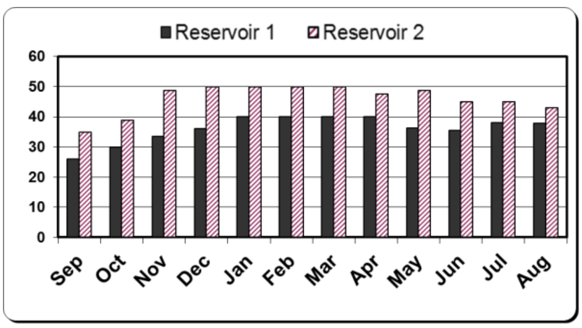

Fig. 5: changes in water height in reservoirs

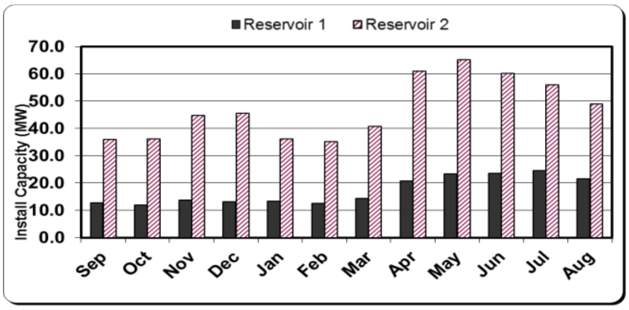

Fig. 6: Powerhouse installation capacity changes in period of time

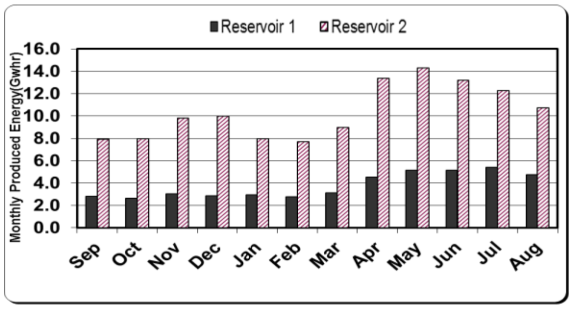

Fig. 7: Monthly changes in energy production in powerhouse in period of time

That is the amount of energy produced by hydropower plants, in terms of kilowatt-hours a month and have: IC: the installation capacity of powerhouse in terms of kilowatt, PF: The plant factor which has been considered 25% for both powerhouses, this means that 25% of working hours in 24-hours works equal to six hours. According to Figures 6 and 7, it can be said, energy production will increase in the wet months of year comparing with other months. The reason is to keep the reservoir empty in these months in order to control probable flood, so height should be reduced for turbine performance and energy production.

The model parameters in the optimal situation: In the powerhouse related to the reservoir 1, August is the highest revenue which is equal to 280.12 million Rials, and November is the lowest income is equal to 91.5 million Rials. The highest and lowest incomes happen in the reservoir 2 in the months of August and October respectively, and the value is equal to 568.33 million riyals and 301.59 million Riyal, respectively. Table 1 shows revenue obtained from sale per unit of energy and total revenue obtained from the reservoirs 1 and 2 in the optimal state. According to Table 1, total revenue obtained from the sale of energy in both reservoirs is equal to 7.06 billion Rials being studied during the period of designing, which is equal to first objective function value.

Table 1: Selling price per unit of energy and the total income of the reservoirs

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Energy price (MW/h) (Rial)	46000	46000	46000	44000	44000	44000	49000	49000	49000	57000	57000	57000
Revenue in reservoir 1 (Million Rials)	105.96	99.88	114.26	103.78	105.95	96.99	130.20	189.02	213.45	248.99	261.42	228.86
Revenue in reservoir 2 (Million Rials)	289.65	299.86	370.92	361.34	287.30	268.87	372.25	555.29	594.59	638.15	593.51	519.94

Table 2: water storage volume in reservoirs 1 and 2 in wet months for controlling the flood (MCM)

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Storage in reservoir 1	-	-	-	-	2319.7	2339.7	2145.5	1690.3	-	-	-	-
Storage in reservoir 2	-	-	-	-	456.9	510.9	347.4	20	-	-	-	-
Total storage volume	-	-	-	-	2776.6	2850.6	2492.9	1710.3	-	-	-	-

Regarding the second objective function of the issue, Volume of the reservoir will be kept empty for controlling the probable flood in each of the reservoirs 1 and 2 from January to April which these values are presented in Table 2.

According to Table 2, it is possible to estimate the total of flood control storage volume during the period of designing, which is equal to second objective function value. This amount is equal to the flood-control storage volume in wet months and in the two mentioned reservoirs which are 9.83 billion cubic meters.

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