SCI-PUBLICATIONS Author Manuscript

Optimization of Reservoir Operation Using Combined Genetic Algorithm and Wavelet Transform Method

[1]L. Ebrahimi, [2]G.A. Barani, and [2]H. Ebrahimi
[1]Water Engineering Department, Shahid Bahonar University of Kerman, Iran
[2]Civil Engineering Department, Shahid Bahonar University of Kerman, Iran

Abstract: Dams construction are high cost projects, and therefore, optimal using of reservoir storages behind dams is an important task in water resources management. In last decades, various optimization techniques have been used for reservoir operation. Among the new methods, Genetic Algorithm (GA) and wavelet transform (WT) have been widely used in recent years. In this study, GA as well as combination of GA and four WT (Coif5, Haar, Db10 and Sym4) has been investigated in optimal operation of Reservoir storages. Using these techniques operation of the multipurpose Vanyar dam reservoir in Tabriz, Iran has been optimized. Results were compared using total monthly square deviation (TSD) of release and demand. The best results were obtained for the case of combined GA and WT sym-4 with least TSD equal to 17.453 and reliability of 84%.

Keywords: algorithm, Wavelet transform, Vanyar dam and Wavelet transform sym-4

INTRODUCTION

Shortage of fresh water resources through the world necessitates conservation of these resources. So dam reservoirs with a huge amount of stored water should operate optimally. To achieve this many optimization techniques such as linear programming, dynamic programming, nonlinear programming and GA have been used to optimize the operation policies of reservoirs.

GA which is based on Darwin's principle of evolution was first proposed by Holland in 1960 and developed by him and his students and colleagues during 1960 to 1970, Goldberg and Deb.[8]. However complete introduction to GA was given by Goldberg[7]. Fahmy et.al[6] used GA to optimize the operation of a reservoir system; they compared results with the dynamic programming results, and stated that GA is potentially applicable for large river catchments. Esat and Hall[5] used GA to optimize the operation of a four-reservoir system, where, the objective was to maximize the benefits of hydropower generation and irrigation water supply subject to constraints on storage and releases from reservoirs. They concluded that the GAs have significant potential for optimization of water resources systems and clearly demonstrated the advantage of GAs over standard dynamic programming techniques in terms of computational requirements. Oliveira and Louks[11] used GAs to develop operating policies of multi-reservoir systems and concluded that

GAs are practical and robust methods of effective operating policies. Wardlaw and Sharif[15] used GA to optimize operation of a deterministic finite horizon multi-reservoir system and concluded that the approach can be easily applied to nonlinear and complex systems. Ahmed and Sarma[2] used GA to determine optimal operation policy of a multi-purpose reservoir. They compared the GA results with the results of dynamic programming (SDP) method and demonstrated that GAs have better performance in comparison with SDP. Wavelet transform was presented for the first time by Grossman and Morlet[9]. Addison et.al[1] used a laboratory model (flume) to investigate turbulent flow around different bodies in different Reynolds numbers in open channels. They used the Mexican Hat Continuous wavelet transform and the Dabchiz discontinuous one and compared the results of these two wavelets. They emphasized on application of wavelet transform in hydraulics. Santos et.al[12], used the Morlet wavelet transform to analyze monthly rainfall data of Matsouyama city to determine the periods of low and high variations. They recommended that this wavelet transform also can be used to analyze erosion model of river catchments. Anctil and Coulibaly[3] used wavelet transform to analyze annual stream flow of south Kebek city in Canada. Tantanee et.al[14] used a wavelet filter and presented a forecasting rainfall model.
In this study, GA and the combined models of GA and four wavelet transforms (Coif5, Haar, Db10 and Sym4)

Corresponding Author: G.A. Barani[2]Civil Engineering Department, Shahid Bahonar University of Kerman, Iran

have been used to optimize the operation policy of the multipurpose vanyar dam reservoir.

MATERIAL AND METHODS

Genetic Algorithm: Genetic Algorithms are stochastic search algorithms that work based on natural evolution principals and in fact, are taken from Darwin theory. Based on this theory, among a population, individuals with more fitness, accept more adaptation and survive, while, those with less fitness have less adaptation and die out. As a result, with spending time, number of individuals with suitable manner and structure increases, and population goes toward evolution and improvement. Since powerful members have more chance for surviving, affect more in producing new generation. So, more number of new generation individuals will be powerful members that usually succeed in competition. Also new generation individuals will have anoxic property of their parent from their genes. In summary, genetic algorithm may be explained as:

1. Problem is stated with genetic language, that is, variables are encoded and usually introduced by strings of 0 and 1
2. An initial population is produced in a probabilistic manner.
3. Pairs of individuals are selected from the initial population as the parents for producing the next generation.
4. The new generation is produced by mating these parents
5. New generation will substitute the previous generation using special procedures
6. Generation process will continue as far as the stopping criteria are satisfied.

This algorithm has the advantages of operating with the coding of parameters set instead of parameters themselves, searching from a population not from an individual, using objective function information and probabilistic transformation methods.

Wavelet transformation: Wavelet transformation is an analytical tool of regular signals for simulation of time information. Through wavelet transformation, a new function will be produced from fundamental functions, such that the main function is mother wavelet and the new function is denoted as daughter wavelet. Wavelet theory is similar to Fourier analysis, but instead of sine and cosine functions of Fourier series, different wavelet functions can be used[13]. Four Wavelet transforms that have been used in this study are as follows:

Haar wavelet: The mathematical relation of Haar mother wavelet is:

$$\psi(x) = \begin{cases} 1 & 0 \le x \le 0.5 \\ -1 & 0.5 < x \le 1 \\ 0 & otherwise \end{cases} \qquad (1)$$

The mathematical relation of Haar scale function is:

$$\phi(t) = \begin{cases} 1 & 0 \le t \le 1 \\ 0 & otherwise \end{cases} \qquad (2)$$

The Haar wavelet curve is presented in Fig (1-a), Chang et.al.(2005) [4].

Symlet wavelet: The symlet wavelets do not have explicit mathematical functions. They are symmetric functions which can be shown by sym N. In this work sym-4 has been combined with G.A. for optimizing the operation of reservoirs. [10], Fig1-b.

Coiflet wavelet: These wavelets in comparison with Daubechies wavelets are more symmetric. Also, these wavelets do not have an explicit mathematical relation. The Coif5 wavelet has been used in this study, Fig (1-c).

Daubechies wavelet: The daubechies wavelets do not have a explicit mathematical function and usually are not symmetric. They are identified by dbN symbol, which N denotes the order of the wavelet. In this study, Daubechies wavelet with order 10 (Db10) has used, Fig (1-d).

c) Coif5 wavelet   a) Haar wavelet
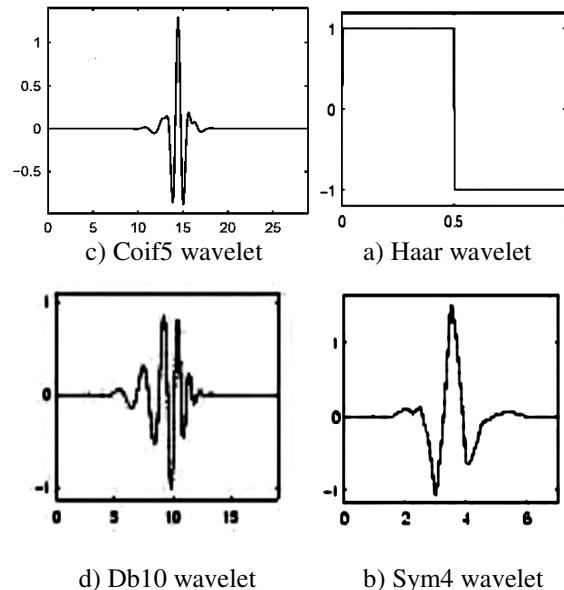
d) Db10 wavelet   b) Sym4 wavelet

Fig. 1: Shapes of used wavelets in combined models Case study (The Vanyar dam reservoir)

The Vanyar dam is built on Agichay river at 5-kilometers north-east of Tabriz city in Iran. The dam site is located at the elevation of 1485-m from sea-level, at $46°\ 23^{/}$ E-longitude and $38°\ 05^{/}$ N-latitude. The storage volume of this dam reservoir at normal pool level is 361.2 million cubic meters. This storage volume can supply irrigation water for 40000 hectares of land. The minimum storage volume of reservoir equals to 84 million cubic meters .The average flow rate of Agichay-river at the dam-site is $14.14 m^3/sec$. In this study, the volumes of 50-years monthly stream flow of the Agichay River have been used. Monthly demands of water and average monthly inflows to the Vanyard dam reservoir are given in table-1.

Table 1: Monthly demand for water and average inflow to the Vanyar dam reservoir

Month	Demand(mcm)	Inflow(mcm)
Apr	25.63	114.03
May	64.58	143.97
Jun	105.7	49.87
Jul	102.64	7.26
Aug	68.05	1.64
Sep	35.37	3.05
Oct	11.45	5.04
Nov	3.11	12.79
Dec	0	15.54
Jan	0	20.98
Feb	6.77	28.26
Mar	7.33	48.64

Optimization model:

Objective function

Minimize $\qquad\qquad g(x)$ $\qquad\qquad$ (3)
Subject to:
$b_i(x) \geq 0$, $\qquad\qquad$ i = 1,2,….,n $\qquad$ (4)
Where x is a m-dimensional vector, and g(x) is objective function. Then, the fitness function may be defined as:

Minimize $\qquad g(x) + r^0 \sum_{i=1}^{n} \phi[b_i(x)]$ $\qquad$ (5)

Where ϕ is penalty function and $r°$ is penalty coefficient. In this study, a value of 100 was found for the penalty coefficient by trial & error. Also the sum of the squared differences between monthly release of water from reservoir and downstream demands is considered as objective function and is defined as follows:

Minimize $\quad g(x) = \sum_{i=1}^{t}(r_t - d_t)^2$, t= 1,2,…12 $\quad$ (6)

where r_t represents released water from reservoir in month t and d_t denotes downstream demand for water in the same month. This type of objective function has been used by Ahmed and Sarma (2005) [2].

Decision variables: In this study 24-decision variables have been used. These variables include monthly release of water from reservoir and reservoir storage volume through a year.

Operation policy: The operation policy used in this optimization model is a linear function as:

$R_t = a_t (S_t + I_t) + b_t$, $\qquad$ t= 1,2,…,12 $\qquad$ (7)

Where R_t represents outflow from reservoir during month t, S_t is storage volume at the beginning of month t and I_t is the monthly inflow to the reservoir at month t. R_t, S_t and I_t are in million cubic meters. Parameters a_t and b_t are constant coefficients of operation policy at month t. So, release of water from reservoir is a function of reservoir storage volume at the beginning of month t and inflow to the reservoir during that month.

Constraints
Storage volume constraints: Reservoir storage volume varies between maximum and minimum levels. The maximum storage volume of reservoir is at the normal pool level (S_{max}) and the minimum storage level is limited to the reservoir dead storage level (S_{min}).

$S_{min} \leq S_t \leq S_{max}$ $\qquad \forall$ t= 1,2,…,12 $\qquad$ (8)
For the Vanyar dam reservoir it is stated as:
$84 \leq S_t \leq 361.2$, $\qquad$ t= 1,2,…,12 $\qquad$ (9)
Where S_t is the reservoir storage volume in MCM.

Outflow constraints: Release of water from reservoir in a particular month should be a positive value greater than downstream demand in the same month.

$D_t \leq R_t$ $\qquad\qquad \forall$ t= 1,2,…,12 $\qquad$ (10)
D_t denotes water demand during month t in million cubic meters.

Continuity Constraint: $S_{t+1} = S_t + I_t - R_t - E_t$ $\qquad \forall$ t , t= 1,2,…,12 $\qquad$ (11)

E_t is the evaporation volume from the reservoir surface during month t in million cubic meters.

RESULTS AND DISCUSSION

Genetic Algorithm: Using G.A approach the operation of the Vanyar dam reservoir is optimized while, inflow to the reservoir and downstream demands (table-1) are considered as model inputs. The outputs of model are optimum reservoir storage volume at the end of each month as well as monthly release of water from reservoir (table-2). Referring to table-2 it is clear that G.A can satisfy demands for water with high reliability, particularly through the dry season.

Percentage of demand satisfying (α) is computed as:

$$\alpha = \frac{R_t}{D_t} \times 100, \qquad R_t = \max(r_t, D_t) \qquad (12)$$

The reliability of demands satisfaction is evaluated acceding to the ratio of number of months with 100% demand satisfaction to the total number of operating months in a year. This reliability for the Vanyar dam reservoir system using G.A optimization approach is evaluated as 67%. Comparison of the downstream demands and releases obtained by the G.A is shown in Fig. 2.
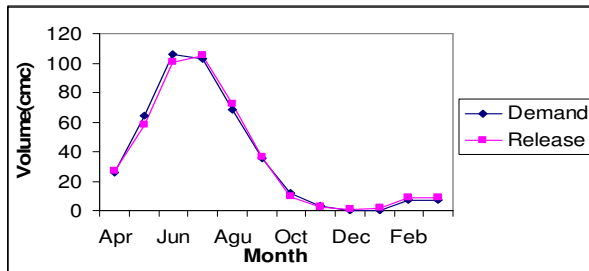

Fig. 2: Comparison of monthly demand and release of water in Vanyar dam reservoir resulted from GA model

Combined G.A and wavelet optimization model: In the present work, the combination of G.A and four wavelets transform (Coif-5, Haar, Db10 and Sym-4) models have been used for optimizing the Vanyar dam reservoir operation. To compare the results of G.A approach with combined models, all parameters of G.A

obtained from trial & error are kept constant and the following change in G.A runs is carried. In Matlab-7 software, the mentioned wavelet transforms have been used to analyze the monthly demands of water and reservoir storage volumes. Implementing wavelet transforms to separate both water demands and reservoir storages in two parts, approximation (ca) and detail (cd). The (cd) values are selected and added to the random values of water demands and reservoir storage in M-File of G.A. This process helps to the faster convergence of G.A to obtain optimum results which are different from G.A results.

Optimum results obtained by applying G.A and four combined models of wavelet transform and G.A were compared, as shown in Table 3 and 4. Optimum values of reservoir releases obtained by G.A and four combined models as well as monthly water demands are shown in Fig. 3
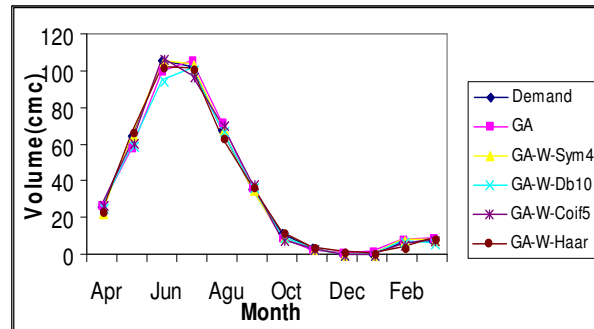

Fig. 3: Monthly demands and releases of water resulted from different optimization models (mcm)

To compare the optimum results of five models, the total square deviations (TSD) are used as:

$$TSD = \sum_{i=1}^{t}(r_t - d_t)^2 \qquad t = 1,2,\dots,12 \qquad (13)$$

The computed TSD values for five models are given in table 5.

The monthly percentages of satisfying demands using the combined model of GA- W- Sym4 are shown in table-6.

The optimum operation policy coefficients obtained using the combined model of GA- W- Sym4 is given in table 7.

Table 2: Optimization results of the Vanyar dam reservoir operation by GA

Month	Optimum storage (mcm)	Optimum release (mcm)	a_t	b_t	(Met of demand)%
Apr	178.5	24.64	0.265	-51.900	100%
May	267.9	57.66	0.243	-42.424	87%
Jun	356.21	100.13	0.421	-74.618	95%
Jul	307.62	105.3	0.516	-57.178	100%
Aug	210.38	71.77	0.465	-34.259	100%
Sep	142.63	36.1	0.345	-15.539	100%
Oct	109.57	9.23	0.196	-14.159	81%
Nov	104.22	2.5	0.097	-8.849	72%
Dec	113.06	0.54	0.086	-10.519	100%
Jan	126.5	1.32	0.112	-15.197	100%
Feb	144.21	8.3	0.213	-28.436	100%
Mar	163.13	8.55	0.091	-13.161	100%

Table 3: Optimum storage volumes (mcm) resulted from different optimization models

Month	GA	GA-W-Sym4	GA-W-Db10	GA-W-Coif5	GA-W-Haar
Apr	178.5	190	180.12	179	182
May	267.9	281.69	268	270.31	272.25
Jun	356.21	360.72	360.54	359.18	342.93
Jul	307.62	350.2	314	302.52	294.7
Aug	210.38	208.42	213.83	219.21	207.86
Sep	142.63	141.81	149.15	153.8	145.63
Oct	113.57	109.25	112.56	116.93	110.22
Nov	108.22	104.26	108.93	114.27	101.75
Dec	117.06	113.96	118.58	122.63	113.62
Jan	130.5	129.5	135	136.37	124.31
Feb	148.21	150.48	156	159.42	144.86
Mar	167.13	170.21	177.3	180	162.13

Table 4: Optimum monthly release of water (mcm) resulted from different optimization models

Month	Demand	GA	GA-W-Sym4	GA-W-Db10	GA-W-oif5	GA-W-Haar
Apr	25.63	26.64	22.34	25.64	27.31	23.44
May	64.58	57.66	64.94	59.66	61.23	66.96
Jun	105.7	100.13	105.39	95.13	106.98	102.64
Jul	102.64	105.3	104.04	101.77	97.37	101.24
Agu	68.05	71.77	68.25	67.37	70.66	64.01
Sep	35.37	36.1	35.61	36.72	38.74	37.24
Oct	11.45	9.23	10.03	9.73	8.33	12.32
Nov	3.11	2.5	3.1	3.11	3.45	3.68
Dec	0	0.54	0	0	0	1.67
Jan	0	1.32	0	0	0.04	1.02
Feb	6.77	8.3	8.01	7.1	5.27	4.33
Mar	7.33	8.55	8.22	6.59	8.23	8.54

Table 5: The computed TSD values of models

Model	GA	GA-W-Sym4	GA-W-Dob10	GA-W-Coif5	GA-W-Haar
TSD	112.541	17.453	142.58	78.896	54.853

Table 6: Monthly percentages of satisfying demands using the GA-W-Sym4 model

Mar	100%
Feb	100%
Jan	100%
Dec	100%
Nov	100%
Oct	87%
Sep	100%
Aug	100%
Jul	100%
Jun	100%
May	100%
Apr	87%

Table 7: Coefficients of optimum operation policy resulted from GA-W-Sym4 model

Month	a_t	b_t
Apr	0.401	-99.576
May	0.365	-90.425
Jun	0.467	-86.355
Jul	0.524	-59.689
Aug	0.602	-58.206
Sep	0.511	-38.413
Oct	0.286	-22.656
Nov	0.185	-18.504
Dec	0.096	-12.432
Jan	0.124	-18.659
Feb	0.225	-34.686
Mar	0.089	-11.256

CONCLUSION

The G.A approach and four combined models of G.A and wavelet transforms were used to optimize the operation of the Vanyard dam reservoir. Results of applying GA showed that downstream reservoir demands can be satisfied with 67% reliability. Among the four combined models, the best results belong to the combined model of GA and W- Sym4 transform with least value of TSD equal to 17.453. So, this model is recommended for the optimization of the Vanyard reservoir operation. Based on the results of this combined model (table-5), the maximum storage volume of 360.72 millions cubic meters is obtained in June, while the reliability of satisfying demand in this month is 100%. It is concluded that, combination of GA and a suitable wavelet transform model can improve the ability of GA to optimize the operation of multipurpose reservoirs.

REFERENCES

1. Addison, P.S., Murray, K.B. and Watson, J.N. ,2001. Wavelet transform analysis of open channel wake flows: Journal of Mechanics Eng.,127(1): 58-70.
2. Ahmed, J.A. and Sarma, A.K. ,2005. Genetic algorithm for optimal operating policy of a multipurpose reservoir: Water Resources Management, 19(2): 145 – 161.
3. Anctil, F. and Coulibaly, P. ,2004. Wavelet analysis of the interannual variability in southern Quebec streamflow: American Meteorological Society, 17(1):163-173.
4. Chang, F.J., Chen, L. and Chen, L.C. ,2005. Optimizing the reservoir operating rule curves by genetic algorithms: Wiely and Sons, ltd. Hydrological Processes, 19(11): 2277-2289.
5. Esat, V., and Hall, M.J. ,1994. Water resource systems optimization using genetic algorithms: 1st Int. Conf. on Hydroinformatics, 1(1): 225-231.
6. Fahmy, H.S. King, J.P.,Wentzel, M.W. and Seton, J.A. ,1994. Economic optimization of river management using genetic algorithms: Summer Meeting, Am. Soc. Of Agricultural Engrs., St. Joseph, Mich. Paper No. 943034, ASAE 1994 Int.
7. Goldberg, D.E. ,1989. Genetic algorithm in search, optimization and machine learning. Addison-wesley pub .co, pp:372.
8. Goldberg, D. E. and Deb, K. ,1990. A comparative analysis of selection schemes used in genetic algorithms: In Foundation of Genetic Algorithms, Morgan Kaufman, Sn Manteo, CA,1: 69-93.
9. Grossman, A. and Morlet, J. ,1984. Decomposition of Hardy functions into square integrable wavelets of constant shape: SIAM J. Mth .Anal, 15:723-736.
10. MATLAB 7.0.0.19920 Help System, Release 14. ,2004. Math Works, Inc.
11. Oliveira, R. and Loucks, D. P. ,1997. Operating rules for multireservoir systems: Water Resource Research, 33(4): 839-852.
12. Santos, A.G., Galvao, C.O., Suzuki, K. and Trigo, R.M. ,2001. Matsuyama city rainfall data analysis using wavelet transform: Annual Journal of hydraulic Eng. JSCE. 45:211-216.
13. Schmidt, J.C. and white, M.A. ,2003. The hydrologic regime of the snake river in Grand Teton national parkand associated channel change: preliminary analysis.cooperative Agreement FA-1200-99-007 Final Report.
14. Tantanee, S., Patamatamakul, S., Oki, T., Sriboorilue, V. and Prempree, T. ,2005. Down scaled rain fall prediction model (DRPM) using a unit disaggregating curve (UDS). J. of Hydrology and Earth System Science Discussions, 2: 543-568.
15. Wardlaw, R. and Sharif, M. ,1999. Evaluation of genetic algorithm for optimal reservoir system operation. Journal of Water Resources Planning and Management, 125(1):25-33.