A NEW METHOD FOR RESERVOIR CONTROL OF DAMS

Aytekin BAĞIŞ[1], Derviş KARABOĞA[2] and Tefaruk HAKTANIR[3]

[1] *Department of Electronic Engineering, Erciyes University, 38039 Kayseri, Turkey*

[2] *Department of Computer Engineering, Erciyes University, 38039 Kayseri, Turkey*

[3] *Department of Civil Engineering, Erciyes University, 38039 Kayseri, Turkey*

e-mail: bagis@erciyes.edu.tr

Key words: Fuzzy Logic Control, Reservoir Control, Fuzzy Controller

ABSTRACT

In this paper, a new and efficient control method based on fuzzy logic is proposed for reservoir control of dams. To demonstrate the performance of the proposed method, we simulate the control system using different probable overflow hydrographs. Simulation results indicate that the proposed method exhibits more desirable and reliable results, and superior performance over the conventional reservoir control method.

I. INTRODUCTION

The reservoir management system is a control system that manages the spillway gate in a dam to increase or decrease the amount of discharge water [1,2]. The most important task of this system is keeping the reservoir water level within a prescribed range. This operation is carried out in order to maximize the energy produced from dam. Because of the hydrological conditions, unfortunately, determining the inflow hydrograph can be extremely difficult if not impossible. Moreover, unexpected nonlinearities may occur due to the uncertain changes during overflows. Therefore, the design of an efficient reservoir operating system is not a simple problem. The objective of this control system is to drive the dam lake level to the desired set points in the shortest time possible by adjusting the spillway gate openness.

Some methods used to achieve the reservoir control have been presented in [3-12]. However, these methods have some problems in controlling the reservoir because of uncertain factors such as inflow hydrograph, sudden changes in reservoir water level, time variation of the amount of water discharged, maximum point of the outflow hydrograph and unsystematic variation of the outflow hydrograph.

In this paper, a new method is proposed for reservoir control of dams. The method is based on fuzzy logic control (FLC) [13-17]. The membership functions used for the representation of fuzzy values are optimally obtained by tabu search algorithm (TSA) [18-24].

FLC and TSA are introduced in the second section. The control problem is defined in Section III. In the Section IV, the proposed FLC designed by TSA is presented. The conclusion is given in the Section V.

II. FUZZY LOGIC CONTROL AND TABU SEARCH ALGORITHM

FLC is based on fuzzy set theory [13-17]. This theory may be considered as the extension of classical set theory. According to fuzzy set theory, it is possible that an element is the member of several sets at the different degree. Fuzzy sets are defined by labels (e.g. big, little, high) and membership functions. Each of the fuzzy sets is characterized by a membership function.

A fuzzy system consists of a set of rules called 'fuzzy rules'. The selection of these rules often relies on an human expert to express the knowledge of appropriate control strategies. Fig.1 shows the main components of a basic FLC system [13,17].

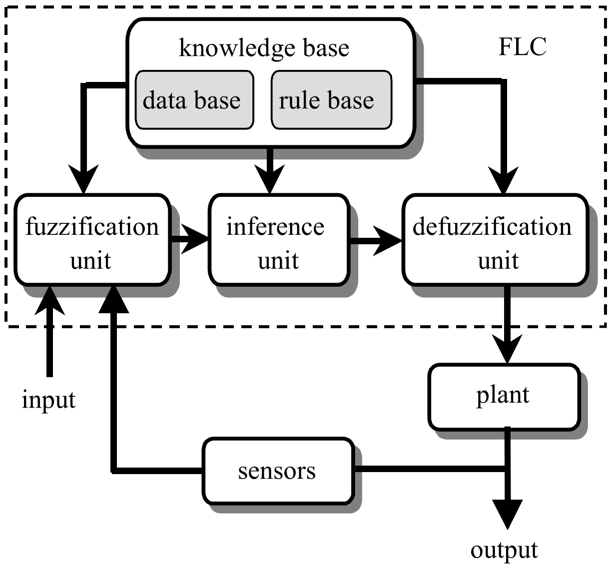

Figure 1. Configuration of a basic FLC

A typical fuzzy controller can be decomposed in four basic components [13]. These are fuzzification unit, knowledge base (data base and rule base), fuzzy inference unit and defuzzification unit.

The main advantage of the fuzzy control method is to control the processes that are too complex to be mathematically modeled. Therefore, the FLC method is a very suitable method for the reservoir management problem [13-17]. The rule base and membership functions have a greate influence on the performance of FLC. Therefore, the membership functions must be optimally determined to design an efficient FLC for a problem. In this work, TSA is used to determine the optimal membership functions.

Tabu search is an effective method for finding good solutions for hard optimization problems [18-24]. This method is based on an iterative search procedure on individual solutions. To forbid some of the search directions and to avoid cycling between the same solutions, TSA employs a tabu list. The information about the past steps of the search is kept in the tabu list. In every iteration of tabu search, the best solution is selected for the next iteration. In order to obtain the tabu list, TSA uses three basic elements: recency memory, frequency memory and aspiration criteria. The recency-based memory prevents cycles of length less than or equal to a predetermined number of iterations. Using the frequency-based memory, the number of change of the solution vector elements is adjusted. If all solution vector elements are classified as tabu, then a least tabu solution element is removed from the tabu list (aspiration criteria). In general, to construct the tabu list, following tabu conditions are used:

Tabu conditions: (recency(n) ≤ rec.K) | or =(frequency(n) ≥ freq.avgfreq)

Here, rec and freq are recency and frequency factors, K is the number of element in the solution vector and avgfreq is the average value of the frequency memory unit.

Finally, tabu search is terminated when some stopping condition is satisfied. A standard TSA is given in Table 1 [13]:

Table 1. Basic tabu search algorithm

(1) Get an initial solution
(2) If stopping criteria is satisfied, stop.
(3) Until the final solution found:
  Produce the neighbour solutions.
  Find the best solution.
    If the best solution is not tabu, assume it as the next solution among the neighbours,
    else if the best solution is tabu and aspiration criteria met, assume it as the next solution,
    else assume the least tabu solution as the next solution
(4) Go to step 2.

III. PROBLEM DESCRIPTION

Dams are necessary structures to provide water supply, flood control, hydropower and irrigation. Simplified diagram of a dam is given in Fig.2 [1].

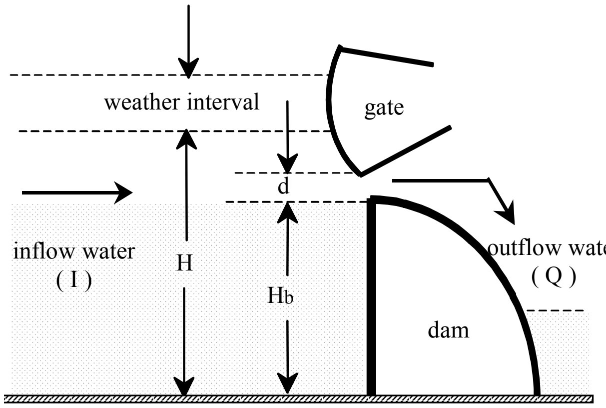

Figure 2. Simplified structure of a dam

In this figure, inflow rate of water to reservoir I, dam lake level H, minimum dam lake level H_b, openness of the spillway gate d and outflow rate of reservoir water Q are also showed. The main aim of the reservoir control system is to keep the reservoir water level within predetermined ranges by adjusting the flow through a spillway gate at the dam in any condition.

Because of the uncertain changes during overflows, fast and effective control of the reservoir is very difficult. Furthermore, human beings are emotional and forgetful. So, humans may reach incorrect decisions under extreme conditions. Therefore, control strategy of the human must be realized automatically so that this disadvantage must be overcomed entirely.

In this study, real data of flood hydrograph of Adana Çatalan Dam in Turkey have been used [5,25,26]. For this hydrologic system, input I(t), output Q(t) and storage S(t) are related to one another by the following equation.

$$\Delta S(t)=[(I(t-1)+I(t))/2-(Q(t-1)+Q(t))/2\ ].\ \Delta t.\ 0.0036.\ 10^6 m^3$$

In this equation, the all discharges are in m^3/s and Δt is in hour. By employing this equation, the relation between new and old capacity for dam lake can be described as

$$S(t)=S(t-1)+\Delta S(t).$$

For the Çatalan Dam, the relation between dam capacity and lake level is reported in Table 2 [5,25,26]. This knowledges are taken from DSI (State Hydroulic Works).

Minimum and maximum values for Çatalan Dam are selected as 118.6 m and 126.44 m, respectively. The water flow is adjusted by opening or closing the spillway gate with settings 0 and 12m. The first knowledges of this work considered are presented in Table 3.

Table 2. Capacity-water level relation of Çatalan Dam

Capacity (10^6 m^3)	Level (m)	Capacity (10^6 m^3)	Level (m)
250	87.5	1108	110
312	90	1250	112.5
370	92.5	1420	115
450	95	1560	117.5
530	97.5	1735	120
635	100	1900	122.5
730	102.5	2120	125
850	105	2310	127.5
970	107.5	2550	130

Table 3. The initial data used in this work

inflow rate (I)	1107.6m^3/s
outflow rate (Q)	750 m^3/s
lake level (m)	118.6 m
change of lake level (dH)	0m/h

In the design of the fuzzy controller, two different probable flood hydrographs are used as given in Fig.3.

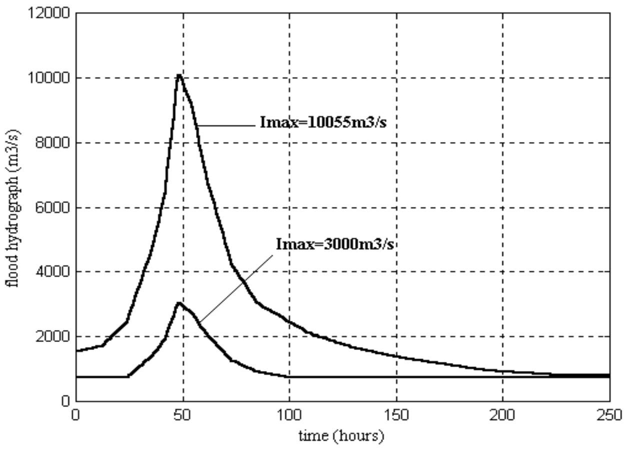

Figure 3. Probable flood hydrographs

IV. THE PROPOSED FUZZY CONTROL SYSTEM

For the reservoir management problem, the proposed fuzzy controlled system is given in Fig.4. Dam lake level (H) and its time rate of change (dH) are selected as the input variables of the FLC. Openness of the spillway gate is the output variable and is controlled by the fuzzy controller.

The main aim of this control problem is to drive the dam lake level to the desired set points ([118.6m and 126.44m]) in the shortest time possible by adjusting the spillway gate openness during overflows.

For H, dH and d, the normalization intervals are selected as [118,127], [-1,1] and [0,12], respectively.

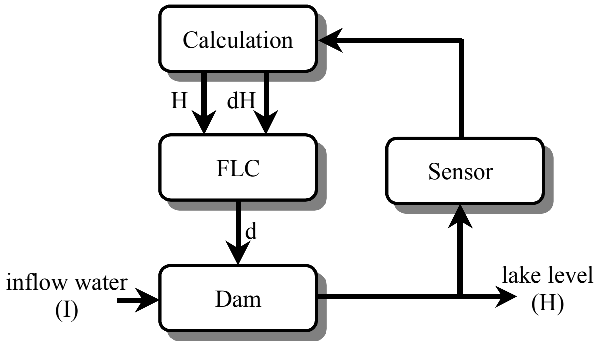

Figure 4. The proposed fuzzy controlled system

Triangular membership functions are used because of their simplicity for fuzzy values. The rule base is intuitively constructed by using 5 rules. Initially, membership functions and rule base are defined randomly. Then, TSA is used to choose the most appropriate parameter values characterizing the fuzzy membership functions.

For this problem, in the design of the fuzzy controller, two main factors are considered by TSA: peak values of outflow hydrograph and changes of these values. During the optimization process, TSA tries to minimize both of them. Thus, an evaluation function can be formed as the following:

$$E= (1/N) \,.\, \left(\sum_{t=0}^{N} \{Q(t+1) + e^{(|Q(t+1) - Q(t)|)}\} \right)$$

where,

- N: number of samples (N=551)
- t: time
- Q: peak value of outflow hydrograph.

In this study, each fuzzy rule base is represented by nine parameters. Thus, for all rules, 45 parameters are used. Therefore, the size of tabu list is determined as 45. The other control parameters used by TSA are given in the following table.

Table 4. Control parameters used by TSA.

tabu list size	45
rec	0.2
freq	2.0
iteration number	250

The membership functions of the FLC optimized by TSA are presented in Fig.5. The rule base used by FLC is also given in Table 5.

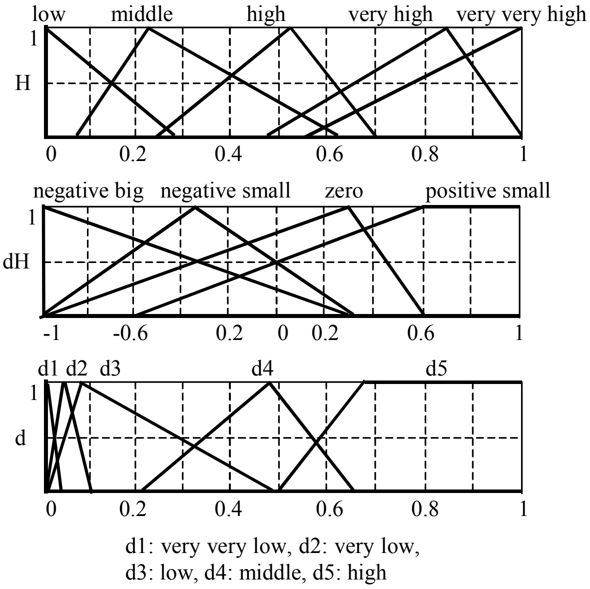

Figure 5. Input and output fuzzy sets optimized by TSA

Table 5. Fuzzy rule base

d dH H	negative big	negative small	zero	positive small
low	--	--	--	very very low
middle	--	--	very low	--
high	--	--	--	middle
very high	--	low	--	--
very very high	high	--	--	--

In this study, Mamdani's max-min inference method is used as a inference mechanism [16,17]. As the deffuzzification method the center of gravity method is employed [16,17].

In Figure 6-7, the suggested fuzzy control system's performance is presented. These figures show that fuzzy control method optimized by TSA represents a very useful tool for solving reservoir management problem. The proposed method not only performs an accurate and efficient solution, but also provides a flexible and sistematic control alternative. Thus, minimum outflow rate and minimum gate openness may be obtained. Also, by cancelling the human factor, the reservoir operating system is done a management mechanism of automatic, entirely. So, the process security is increased.

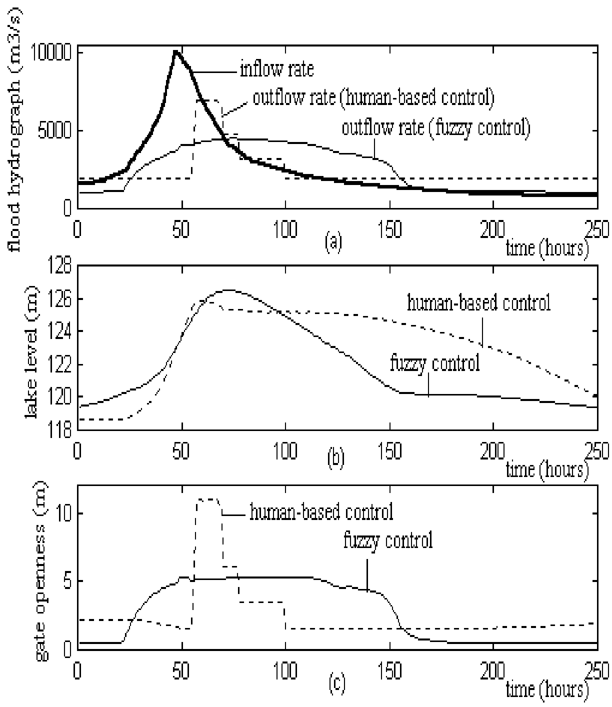

Figure 6. Performance characteristics for fuzzy-based and human-based control systems (for Imax=10055m^3/s)

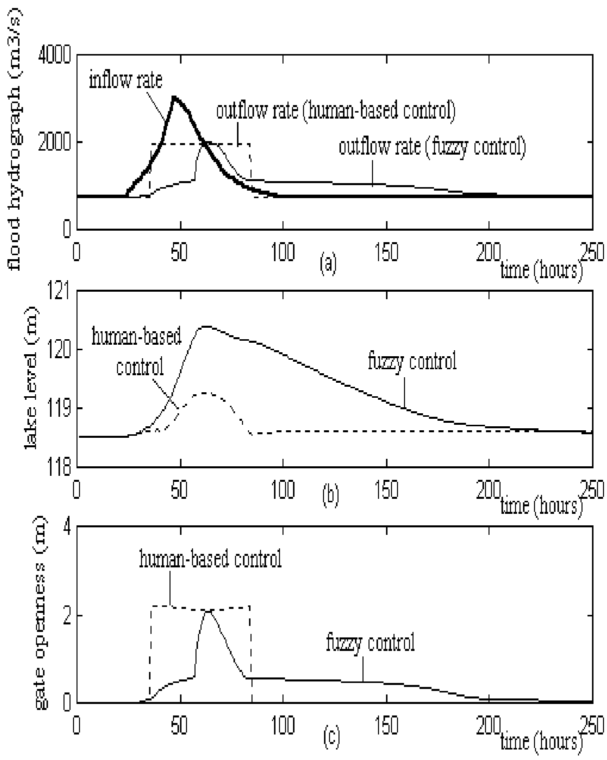

Figure 7. Performance characteristics for fuzzy-based and human-based control systems (for Imax=3000m^3/s)

V. CONCLUSION

In this paper, an efficient and accurate method based on fuzzy control is proposed for the reservoir operating system in dams. Because optimization of the membership functions is an important factor, for the success of optimum reservoir control during overflows, a TSA is also used in this work. The simulation results show that the fuzzy logic-based control optimized by a TSA provides an appropriate alternative and is not based on human operators. Therefore, the drawbacks of the human-based control system are not exist in this method. Moreover, the parameters of the membership functions are optimized by using a TSA and the degree of automation of the fuzzy control system is increased.

VI. REFERENCES

[1] S. L. Udall , Design of Small Dams, United States Department of The Interior, Bureau Of Reclamation, Washington, 1961.

[2] V.T.Chow, D.R.Maidment & L.W.Mays, Applied Hydrology, McGraw-Hill, New York, 1988.

[3] T.Haktanir & Ö.Kisi, Ten-stage discrete flood routing for dams having gated spillways, Journal of Hydrologic Engineering (2001), 86-90.

[4] N.Acanal & T.Haktanır, Five-stage flood routing for gated reservoirs by grouping floods into five different categories according to their return periods, Hydrological Sciences-Journal-des Sciences Hydrologiques 44(2), (1999), 163-172.

[5] Ö. Kişi, Optimum ten-stage overflow operating model for dams having gated spillway, Thesis, Turkey Erciyes University 1999.

[6] W.Yeh, Reservoir management and operations models: a state of the art review, Water Resour. Res. 21(12) (1985), 1797-1818.

[7] S.P.Simonovic, Reservoir systems analysis: closing gap between theory and practice, J Water Resour. Plng. And Mgmt., ASCE 118(3) (1992), 262-280.

[8] R.A.Wurbs, Reservoir system simulation and optimization models, J Water Resour. Plng. And Mgmt., ASCE 119(4) (1993), 455-472.

[9] A.J.Raudkivi, Hydrology: An Advanced Int. to Hydrological Processes and Modeling, Pergamon Press, New York, 1979.

[10] R.G.Mein & T.A.McMahon, River And Reservoir Yield, Water Res. Pub., Littleton, Colo, 1986.

[11] D.P.Loucks, J.R.Stedinger & D.A.Haith, Water Res. Systems Planning And Analysis, Prentice Hall, N.J., 1981.

[12] D.J.Thampapillai & W.F.Musgrave, Flood damage mitigation:a rev. of str. and nonstr. measures and alt. decision frameworks, Water Resour. Res. 21(4) (1985), 411-424.

[13] D.T.Pham & D.Karaboğa, Intelligent Optimisation Techniques; Genetic Algorithm, Tabu Search, Simulated Annealing And Neural Networks, Springer-Verlag, London, 2000.

[14] M.Sugeno, An introductory survey of fuzzy control, Information Sciences 36, (1985), 59-83.

[15] T.J.Ross, Fuzzy Logic with Engineering Applications, McGraw-Hill, 1995.

[16] G.J.Klir, U.S.Clair & B.Yuan, Fuzzy Set Theory: Foundations and Applications, Prentice Hall.PTR., 1997.

[17] C.C.Lee, Fuzzy logic in control systems: fuzzy logic controller-part II, IEEE Trans. On Systems, Man, and Cybernetics 20(2) (1990), 419-435.

[18] F. Glover, Tabu search-part I, ORSA Journal on Computing 3 (1) (1989),190-206.

[19] F. Glover, Tabu search-part II, ORSA Journal on Computing 1 (2) (1990), 4-32.

[20] F. Glover, A user's guide to tabu search, Annals of Ops. Res. 41 (1993), 3-28.

[21] R. Chelouah & P. Siarry, Tabu search applied to global optimization, Europen Journal of Operation Research 123 (2000), 256-270.

[22] D. Karaboğa, Design of fuzzy logic controllers using tabu search algorithm, Biennial Conf. Of the North American Fuzzy Inf. Processing Society (1996), 489-491.

[23] A. Bağış, N. Karaboğa & D. Karaboğa, System identification using tabu search algorithm, TAINN , 2000.

[24] B. L. Fox, Integrating and accelerating tabu search, simulated annealing, and genetic algorithms, Annals of Operations Research 41 (1993), 47-67.

[25] General Directorate of State Hydraulic Works, Storage-area relationship and the design flood hydrographs of the Catalan dam and hydropowerplant, Project No. HD-003, Division of Dams and HPPs, Yucetepe, Ankara, Turkey, (1987a).

[26] General Directorate of State Hydraulic Works, Spillway rule curves of the Catalan dam and hydropowerplant, Project No. HD-004, Division of Dams and HPPs, Yucetepe, Ankara, Turkey, (1987b).