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Operation Of Spillway Gates Using Modern Fuzzy Logic Based Technique: A Case Study Of Ukai Dam's Spillway

KEYWORDS: Fuzzy Logic,Soft-computing techniques, Gated Spillways, Real-time operation, Reservoir operation.

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ABSTRACT Fuzzy logic is one of the emerging advanced soft computing modern technique which can be used to efficiently control real time spillway gates' operation of a reservoir during high inflow. Operation of gated spillway is a very important aspect in real time reservoir operation. It is usually done based on the manual control using rule curves or by making some special guidelines proposed by concern committee for the particular dam. This paper present study of fuzzy logic for high inflow in Ukai reservoir using real time data of reservoir to control spillway gates. In this study, the performance of Fuzzy Logic based model is demonstrated using high inflow events. The comparison of the fuzzy logic based model's outflow and past actual outflow of dam is done.The proposed control method is the most systematic approach and produces smoother hydrograph, since it discharges the water in proportion to the overall severity of the incoming flood hydrograph.

1. INTRODUCTION

Gated operation of a spillway is the art of releasing water through gates during high inflow/flood. In the flood or monsoon season when extreme rainfall causes the increase in reservoir then surplus water may be discharge through gates installed in it. The gated operation is also sometimes done as per reservoir routing. In reservoir routing by knowing the upstream flow conditions one can easily determine the downstream hydrograph. But the reservoir is also maintained at certain level so that it gets filled in monsoon and stored water can be utilised throughout the year for multipurpose requirements such as water supply, irrigation, hydropower etc. Rule Level for a reservoir should be maintained and followed. Routing can be done by various methods and here fuzzy logic based technique is employed. The aim of this fuzzy logic based control system is to adjust the dam Elevation as per rule level and to effectively manage the flood during high inflows of short durations by adjusting the openness of spillway gates.

Reservoir control is achieved by operation of spillway gates. A deterministic operating procedure for reservoir control were presented initially by Beard (1963)[3], Windsor (1973)[18], Can and Houck (1984)[4], Ozelkana et al. (1997)[13], Sakakima et al. (1992)[15], Oshimaa and Kosudaa (1998)[12] and Chang and Chang 2001[5]proposed strategies related to build an optimal reservoir operation system.

KarabogaDervis et. al.(2004)[10] used Fuzzy Logic in operating spillway gates and Haktaniret. al. (2013)[8] gave a fifteen-stage operation policy for the routing of flood hydrographs. The application of Fuzzy logic is vast and study by various researchers can be traced such as byRussel and Campbell 1996[14], Shrestha et al. 1996[16], Cheng and Chau 2001[5],Jolma et al. 2001, Kumar et al. 2001 and KarabogaDervis(2004)[10]. These have applied the Fuzzy logic in various trends of reservoir operation. Russel and Campbell 1996[14]and Shrestha et al. 1996[16]gave fuzzy programming based optimization of reservoir operation, rule based model by.

2. STUDY AREA

Ukai Dam is situated on Tapiriver at Ukai, Gujarat, India is selected as study area. Figure 1 shows the Ukai dam and reservoir.

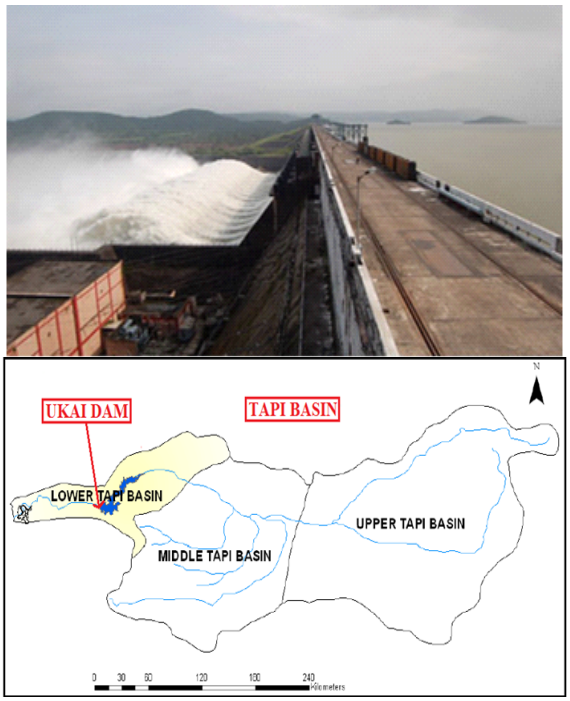

Figure 1: Ukai dam and Tapi basin

3. RESERVOIR OPERATIONS DURING HIGH INFLOWS

Reservoir operation is quite difficult due to uncertainties in inflow in reservoir. A reservoir can be operated as long term or short term (Real-time reservoir operation). Gated operation of a spillway employs a real-time reservoir operation. A real-time reservoir operation is a very complex problem, for the high inflow for gated spillways. A reservoir is constructed for servingmultipurpose.A proper efficient reservoir operation should fulfil all needs and demands which are required. High Inflow usually plays important role in the Reservoir operation and hence, Reservoir control policies have to be adopted to control the outflow to the downstream, to maintain the storage and elevation levels, to manage the high inflow or flood. Satisfying all demands is the main objective of the study under reservoir operation

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management in high inflows or flood. Also, the structure of the dam and spillway must be safe. Operation of spillway gates forms a major part of study during a flood control problem.

Reservoir control and operation has been done by the U.S. Army Corps of Engineers, (Hydrological 1987). The gates of a spillway should be operated according to the probable inflow hydrograph as given by Haktanir and Kisi (2001)[7].

4. FUZZY LOGIC BASED MODEL DEVELOPEMENT

Gated operation employs real-time reservoir operation which aims in controlled release of water. The aim of this fuzzy logic based control system is to adjust the dam Elevation as per rule level and to effectively manage the flood mitigation for high inflow. Factors affecting reservoir systems are inflow variations, unexpected changes in reservoir level, amount of dischargeper unit time, maximum possible outflow etc. In this paper,gated operation using fuzzy logic based model is discussed.

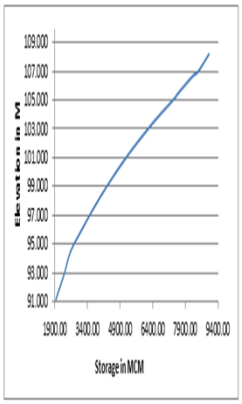
The main variables of a reservoir system are the inflow rate I(t), [m3/s], outflow rate, Q(t), [m3/s], reservoir capacity, S[106 m3], minimum reservoir water surface elevationHmin [m], actual water level, H [m],and spillway gate opening d [m] (Fig. 2). The accumulation of storage in a reservoir depends on the difference between the rates of the inflow and outflow. For the time interval of Dt, this continuity relationship can be expressed as the following (Udall 1961):

$$\Delta S(t)=I(t).\Delta t-Q(t).\Delta t$$

Where, ΔS(t)storage accumulated or depleted during.Δt; and I(t)/Q(t)= average rate of inflow/outflow during .Δt.

Table 1: Elevation (in feet and m) and Storage relation for Ukai Dam

Elevation in ft.	Elevation in m	Storage in MCM	Elevation in ft.	Elevation in m	Storage in MCM
299	91.135	1960.00	330	100.584	4979.39
300	91.440	2018.36	335	102.108	5714.86
305	92.964	2348.16	340	103.632	6524.02
310	94.488	2630.21	345	105.156	7414.28
315	96.012	3149.90	346	105.461	7553.19
320	97.536	3704.00	350	106.680	8235.19
325	99.060	4311.05	351	106.985	8480.18



Reservoir routing is used to find the outflow hydrograph. Elevation-Storage and Elevation-Discharge are used to find out the outflow hydrograph for the Inflow in a river. Table 1 gives the Elevation and storage relation for the Ukai Dam, Tapi basin.

In the fuzzy control system design, the selection of the controller structure involves the following choices.

A. Input and output parameters.

The input variables for the fuzzy controller are elevation(H) and rate of change in Inflow(dQ). The output of the controller is gate opening (d). The outflow rate of the reservoir is controlled by the gate opening tuned by the fuzzy logic based model. For the H, dQ, and d variables, the normalization intervals can be selected as follws: For H: [FRL PMF], for dQ: [-1, 1] and for gate opening [0 to max. gate opening] respectively. FRL: free reservoir level, PMF: probable maximum flood.Figures 2 & 3 shows the schematic representation of the gates for the spillway and the strategy to be used in fuzzy logic program.

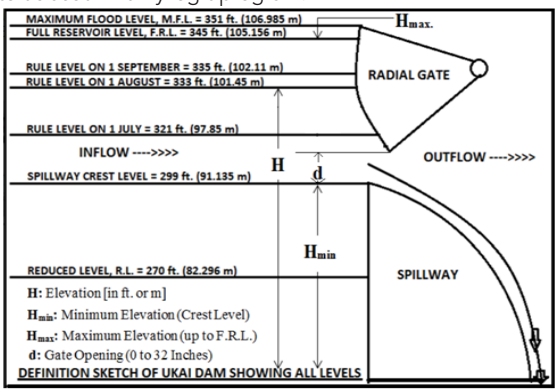


Figure 2. Schematic sketch of the gated spillway

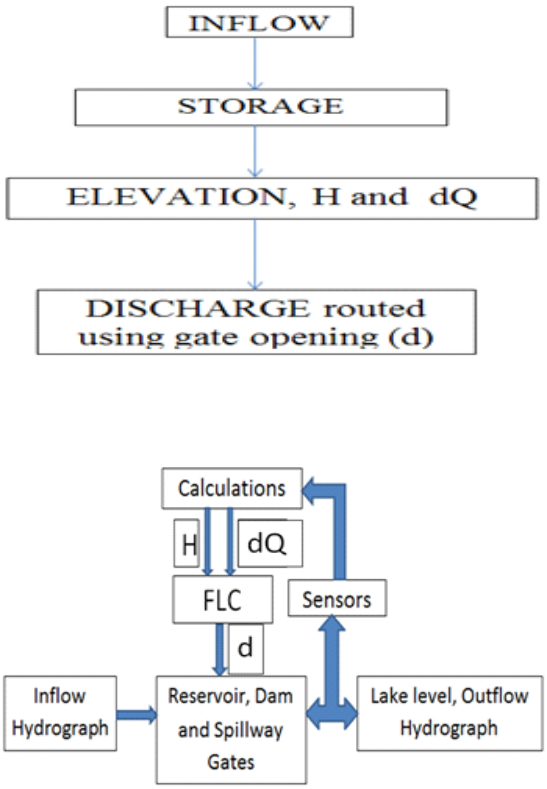


Figure 3. Proposed Fuzzy Logic based model's Control System

B. Membership functions for parameters.

The membership functions used for the fuzzy values of the fuzzy parameters are selected based on expert experience and users intuition. All of the fuzzy values are represented by triangular membership functions for simplicity; here five membership functions have been used.

C. Rule structure.

The rules of the fuzzy logic based model are obtained from information gathered by engineers and experts informed about the dam, and operator experience. The rule base of the fuzzy logic model contains rules, which can also be tabulated in Table 2.

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Table 2: Relation developed for Fuzzy Logic program between membership function

H dQ	Negative big	Negative small	Zero	Positive small	Positive big
Very low	Very low	Very low	Very low	Very low	Very low
Low	Low	Low	Low	low	low
Medium	Medium	medium	medium	medium	medium
High	High	High	High	high	high
Very high	Very high	Very high	Very high	Very	Very

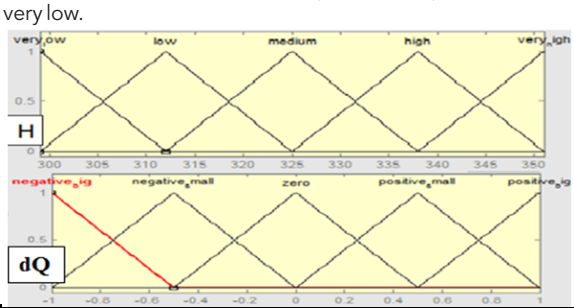
D. Inference mechanism. The output of each rule is determined by Mamdani's max-min inference method.

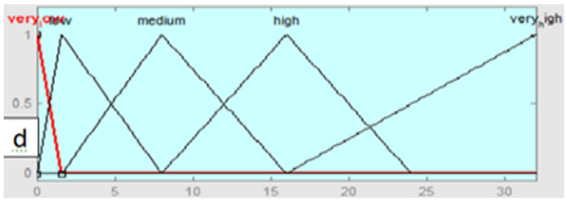
E. Defuzzification method. The standard center of area (Centroid) method is employed forthe defuzzification process,.

Table 3: Range of Membership Function for Rule level (1 September to 30 September)

H	SPILLWAY CREST TO MFL (299 ft. TO 351 ft.)			dQ	NEGATIVE BIG TO SMALL BIG (-1 TO 1)			d	Zero to maximum opening (0 to 32 Inch)		
Very low	335	335	339	Negative big	-1	-1	-.5	Very low	0	0	0.4
Low	335	339	343	Negative small	-1	-.5	0	Low	0	0.2	1.6
Medium	339	343	347	Zero	-.5	0	.5	Medium	0.2	1.6	2.4
High	343	347	351	Positive small	0	.5	1	High	2	4	8
Very high	347	351	351	Positive big	.5	1	1	Very high	6	24	32

Figure 4 represents the membership functions and other details used in development of fuzzy logic based model. The boundary points for dQ will be -1 and 1. The set points for I are considered as 0 and 12. The following rule base is initially constructed randomly. A few examples may be:(i) If dam Elevation (lake level) is low and rate of change of Inflow is small positive then the openness of spillway gate is very low. (ii) If dam Elevation (lake level) is at middle and rate of change of Inflow is zero then the openness of spillwaygate is very low.





(a)

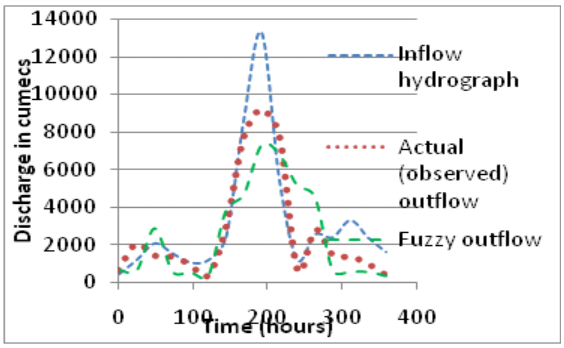
S. No.	Parameters	Description
1.	Input parameter:	H (Elevation), dQ (change in Inflow)
2.	Output parameters	d (Gate opening)
3.	Membership function for each parameter H dQ d	5 5 5
	Total number of rules derived for program, in fuzzy logic tool:	25
5.	Membership function used:	Triangular membership function
6.	Inference mechanism	Mamdami type Inference mechanism
7.	Highest Flood Level	351 ft.
8.	Spillway Crest	299 ft.
9.	Full Reservoir Level	345 ft.

(B)

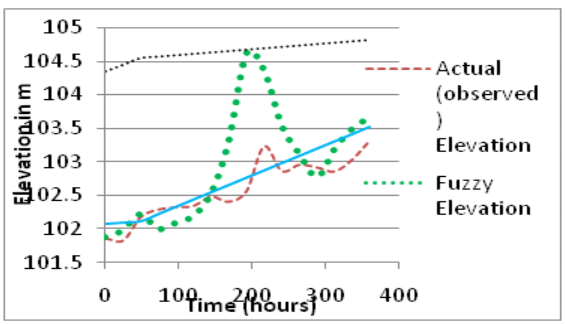
Figure 4. (a) Membership functions used for Input and output and (b)Different Parameters Used In Fuzzy Logic System

5. CASE STUDY AND RESULTS

The High Inflow event of the year 2012 of Ukai dam has been taken and studied for the application of fuzzy logic in study. Figure 5 shows the inflow hydrograph followed by actual and simulated elevation results based on fuzzy logic based model.



(a)



(b)

Figure 5: Performance characteristics of fuzzy logic based model for year 2012 compared with observed Elevation and rule levels.

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5.1 High inflow event of 2012: The statistical parameters have been computed. The root mean square error (RMSE) 0.45, inequality coefficient (U) is 0.0033 and discrepancy ratio (D.R.) is 1.0032. The statistical parameters are within limits and shows good agreement between observed and predicted values. For the high inflow/flood event of year 2012 the model over predicts within the confidence limit of 2 percentas shown in figure 6, which itself shows a good agreement between model and controlled approach.

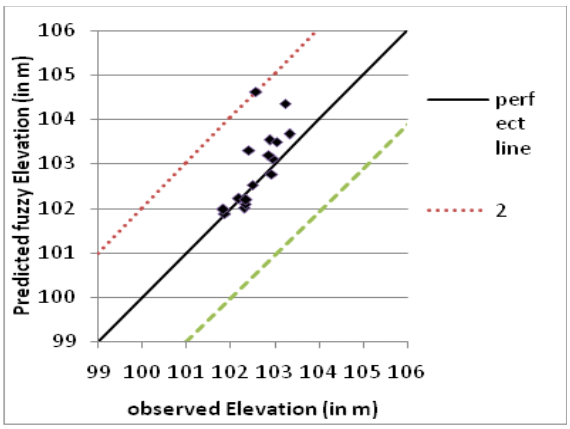

Fig. 6. Predicted Fuzzy Elevation v/s Observed Elevation for high inflow of 2012

6. CONCLUSION

Following findings can be summarized as a result of present study,

1. The control operation can be carried out automatically without requiring any human operator interference. The fuzzy logic based Model does not require a mathematical model.
2. The proposed model presentsa systematic approach, since water discharging is in proportion to theoverall severity of the incoming high inflow.
3. The fuzzy logic based model produces smoother outflow hydrographs than those obtained by actual.
4. The case study of the year 2012 shows that the results are in good agreement with the observed flood and are within 2 percent confidence limit.

The proposed fuzzy control method performs as an accurate and reliable control alternative when it is compared with the conventional control techniques.

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