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Fuzzy Based Decision System for Gate Limiter of Hydro Power Plant

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Abstract

Starting sequence of the hydropower plant checks various inputs such as sump oil level, oil pressure, available head etc. Operator sets maximum gate opening according available head. Ambiguity involved in the operator's setting. This ambiguity is attempted to model by developing a Fuzzy Inference Scheme (FIS). Simulation model is developed using fuzzy tool in MATLAB. The model is studied for different types of membership function (MF) and Defuzzification. The experience of the operator and available documentation is utilized to design FIS for gate limiter.

This paper presents the use of Fuzzy Logic in hydro power plant (HPP) to decide maximum opening value for gate. The fuzzy logical decisions found to be in good agreement with operators manual setting after adequate tuning of FLC.

Keywords: Hydropower plant, MATLAB Simulation, Gate limiter, Fuzzy Logic.

Introduction

Hydro Power Plant staring sequence goes through prestart check. Prestart checks confirms status of mechanical parts such as oil level, guide vane lock while start checks verify circuit breaker open and guide vane closed status. While starting the Power Plant Operators compute head available and decides maximum gate opening limit.

The main objective of the control system is to generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the voltage and frequency within permissible limit. The main controls in Hydroelectric Power Plant is hydraulic turbine governor and excitation control. Hydraulic turbine governor control the speed of the turbine according to load variation. Reactive power requirement is controlled by Excitation system [1].

The Gate control plays an important role in the control of hydroelectric power plant. The gate opening controls the flow of water through turbine. The gate opening defines the amount of water flow through turbine. While starting the HPP, the operator set maximum gate opening limit value according to head available. This Gate opening should not exceed the maximum gate opening value set by the operator.

At first gate opens at 18% the turbine rotates at no load (spinning speed). This gate opening controls the frequency of the generation at no load. When frequency and phase of the generator match with the grid frequency and phase, the generator connected to the grid. The gate control in interconnected system control load and frequency of the generation. Here we introduce fuzzy logic to set gate opening limit value.

Fuzzy Based System

In the operation of HPP expert utilizes his experience to decide maximum gate opening value. At first gate opens at 18% then turbine rotates at no load [6]. Hydro generator connects to grid, when synchronized. Gate opening in interconnected system decides generation. This gate opening value should not exceed the maximum gate opening value decided by operator.

Here we developed a fuzzy optimized system for small HPP. In present paper Fuzzy control systems are described for defining the turbine gate maximum opening value. The present paper reports the Decision Making for most advantageous gate limit value. We used triangular and bell shape membership function in conjunction centroid and bisector defuzzification method.

The gate limiting value is depends upon head available. If the gate opening exceeds the optimal value for a particular value of head, it damages the system. The fuzzy base system reads the available head value by using head measuring system and decides the optimal gate limiting value. The fuzzy based scheme decides the Gate Maximum opening limit value required for protection of system.

Drawbacks of old System

1. Ambiguity in setting gate opening limit value.
2. Expert is require to operate HPP

Fuzzy Inference System (FIS)

Fuzzy Inference process formulates the mapping of a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions are made. The process of fuzzy inference includes membership functions, fuzzy logic operators, IF-THEN rules and knowledge base. The fuzzy based system decides the gate opening limit value to avoid the damage.

The fuzzy Module Includes [2, 4, 8]

- Fuzzification
- Inference scheme
- Defuzzification

The structure of FIS module is depicted in fig.1.

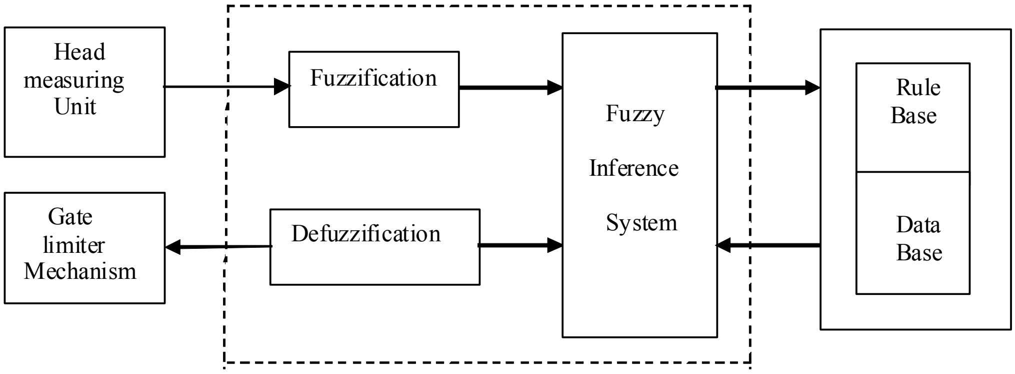

Figure 1: Fuzzy Module for FIS

Input Scaling and Fuzzification

The fuzzification stage is determined by the choice of the range, shape and number of the membership functions [3]. This is achieved with the different types of fuzzifiers. There are generally three types of fuzzifiers, which are used for the fuzzification process; they are

1. Singleton fuzzifier,
2. Gaussian fuzzifier, and
3. Trapezoidal or triangular fuzzifier.

We visited to the Kanher HPP to understand its control process. It is located near to Satara (Maharashtra) at about 10 Km. We had prolonged discussion with HPP engineers. From the discussion we found that scaling of available head into the form of fuzzy sets is quite ambiguous. The head available varies from 9 to 31 meter. So fuzzification of Head is carried out to define maximum limit of gate opening.

We take the Head value from the measuring instrument as an input for fuzzification to FIS. The head measuring system is basically water level difference measuring unit in combination with the water level indicator. Head measurement system provides crisp value. The fuzzy set for input variable Head is defined in Table 1. Here we define highest Head by membership function VH and lowest by VL. The Triangular shape and Bell shape membership Functions for input variable Head is shown in Fig 2a and 2b.

Table 1: Fuzzy set for Head

For Triangular Shape Membership Function	For Bell Shape Membership Function
μ_{VL} (H) = L (H, 9,15)	μ_{VL} (H) = (2.001 9.7)
μ_{L} (H) = Λ (H, 9, 13.6, 19)	μ_{L} (H) = (2.423 15.2)
μ_{M}(H) = Λ (H, 15, 19, 25)	μ_{M}(H) = (1.97 20.43)
μ_{H} (H) = Λ (H, 19.52, 24.62, 30.12)	μ_{H} (H) = (2.1 24.83)
μ_{VH} (H) = Γ (H, 24.9 31)	μ_{VH} (H) = (1.53 28.8)

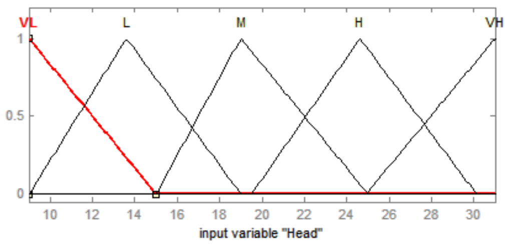

Figure 2a: Triangular shape Membership functions for Head

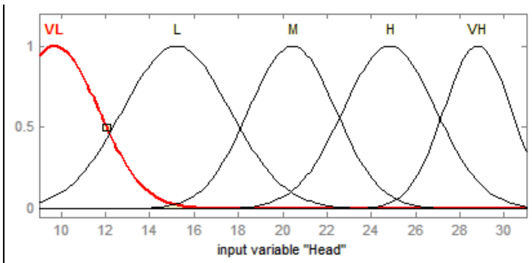

Figure 2b: Bell shape Membership Functions of Head

Output Scaling and Fuzzification

Depending upon the available Head system decides the gate maximum opening limit. From the discussion we conclude that the limit point for gate opening varies in range of 60% to 100%. [6] So the range for Gate opening limit is defined between 60% -100 %. For FIS output variable “Gate opening limit (GL)”, the membership function is as shown in fig.3a for triangular shape MF and fig. 3b for bell shape. The gate opening limit is classified into five fuzzy partitions labeled respectively as Small, Little Small, Medium, Little Large, and Large. The linguistic values are chosen as given in Table 2.

Table 2: Fuzzy set for Gate opening Limit

Triangular shape Membership Function	Bell Shape Membership function
μ_{S} (GL) = L (GL, 60,67.1)	μ_{S} (GL) = (2.48 59.17)
μ_{LS} (GL) = Λ (G, 61.9, 70.11, 79)	μ_{LS} (GL) = (2.51 68.3)
μ_{M} (GL) = Λ (G, 72.6, 80.2, 90.2)	μ_{M} (GL) = (2.647 78.1)
μ_{LL} (GL) = Λ (G, 80.19, 88.29, 96.69)	μ_{LL} (GL) = Λ (1.59 86.73)
μ_{L} (GL) = Γ (GL, 91.69)	μ_{L} (GL) (2.589 95.8)

The term set for labels of fuzzy set is: S = “Small”, LS = “Little Small”, M = “Medium”, LL = “Little Large”, L = “Large”. FIS accepts Head value as an input provided by the head measurement system and goes for the computation of gate opening limit.

The membership Functions for output Gate Limit value of FIS is shown in Fig 3a and 3b.

The gate maximum opening limit value is an input for gate limiter mechanism. It does not allow gate opening beyond preset value.

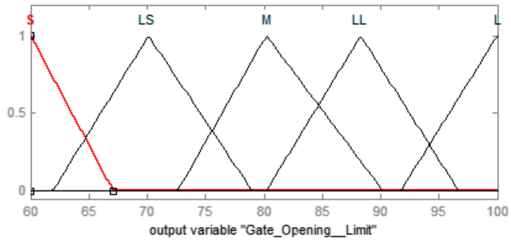

Figure.3a. Triangular Membership functions for gate maximum opening value "GL".

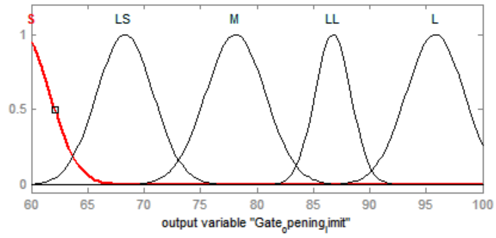

Figure.3b. Bell shape Membership function for gate opening limit value "GL".

Inference Rule for FIS

FIS generates the fuzzy decision intending to decide the Gate opening limit value GL. The gate opening is dependent on head available. From the discussion with HPP engineer and skilled operator, gate opening settings done by skilled Operator were analyzed. If the Head available is very low then gate opening limit is large and if it is very high then gate opening limit is small. That is as Head value decrease the gate opening limit increases. By measuring Head, operator decides the gate opening limit to adequate discharge and generation. This operator's decision mechanism about GL value selection based on Head available is formulated in the form of IF-THEN rules. Rules are framed in the following format,

IF Head is VH **THEN** Gate opening limit is S

We have five linguistic levels of Head input and five linguistic levels of Gate opening output. So this rule base is composed of 5 rules as given in Table-3. The rules are defined such that the decision output resembles the human expert operator's selection process as an expert.

Operator decision about gate maximum opening limit based on Head available is formulated in the form of rule as follows.

Table-3: Inference Rule for Gate opening Limit

<table>
<tr><td rowspan="5">IF
Head "H' is</td><td>VH</td><td rowspan="5">THEN
Gate Opening Limit "GL" is</td><td>S</td></tr>
<tr><td>H</td><td>LS</td></tr>
<tr><td>M</td><td>M</td></tr>
<tr><td>L</td><td>LL</td></tr>
<tr><td>VL</td><td>L</td></tr>
</table>

Inference Scheme [4]

Mamdani's individual rule based fuzzy logic inference is utilized in our system. It computes the overall decision outcome based on the individual contribution of each rule in the rule base. In the inference process each rule is individually fired depends on crisp value of input variable (Head available) from fuzzification module. In this process clipped fuzzy set formed, which represent the overall fuzzy output variable as shown in fig.4a for triangular shape and fig. 4b for bell shape MF. These clipped fuzzy set are then aggregated to compute single value.

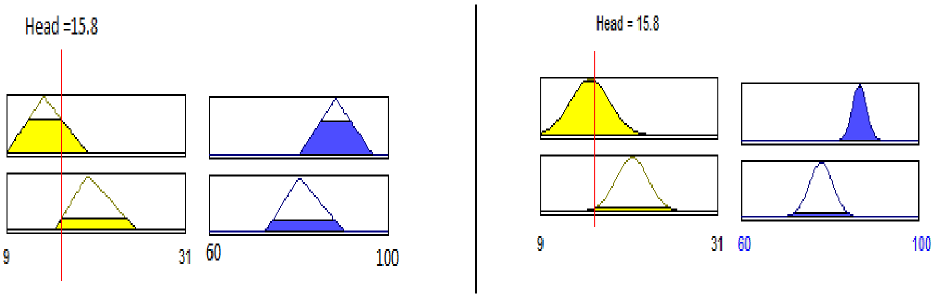

Figure 4-Mamdanis Fuzzy Inference scheme, (a) Triangular shape MF (b) Bell shape MF

Defuzzification [5, 7]

It is the last step in fuzzy Inference scheme [4, 5]. It is carried out to find a compromise value from all clipped fuzzy sets that represent the overall fuzzy output variable. It converts each fuzzy output variable resulted in inference process into the crisp value.

Here we employ centroid defuzzification and bisector defuzzification method [2, 5]. The centroid method is illustrated in fig. 5a and that of bisector defuzzification method in fig.5b that computes limit point of gate opening required to adequate discharge and generation. The system results are carried using MATLAB Software GUI tool.

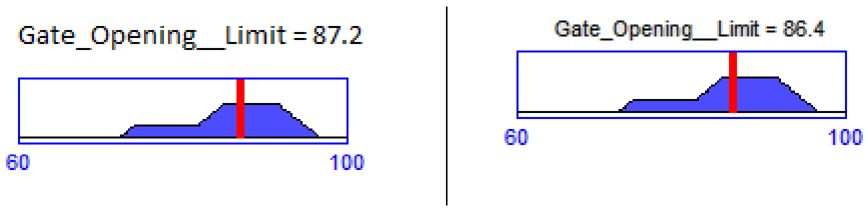

Figure 5: Defuzzification View for (a) Bisector (b) Centroid Defuzzification,

When system is put to work, it checks the head available and then sets gate maximum opening value. Both input and output variables are represented with triangular and bell shape membership functions. First the ranges of these membership functions were defined and the model was simulated to see the simulation result. Membership functions were tuned by reshuffling the peaks or/and ranges of fuzzy sets by 'Trial and Tune' process in iterations to obtain optimized fuzzy sets for input and output. These optimized fuzzy sets are as shown in Table 1 and 2. We have studied all combinations of mentioned MFs and defuzzification methods for Gate opening limit value. Figs 6a, 6b, 6c & 6d show the surface view of FIS for the each combination.

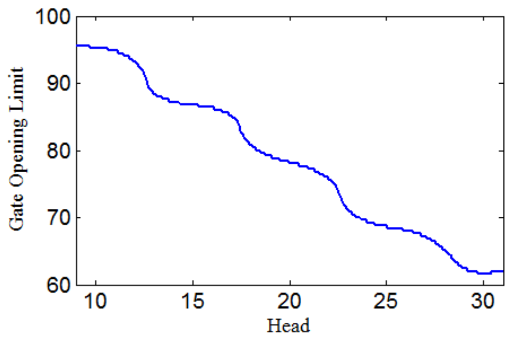

Figure 6a: Surface view of Bell shape MF & Bisector Defuzzification Method.

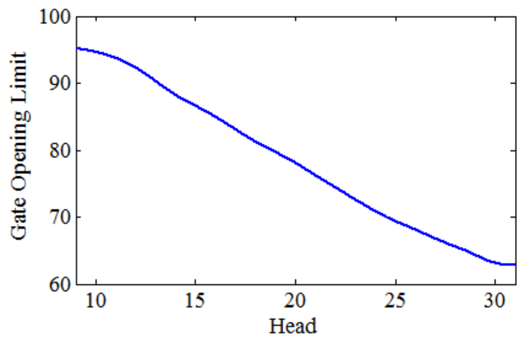

Figure 6b: Surface view of Bell shape MF & Centroid Defuzzification Method.

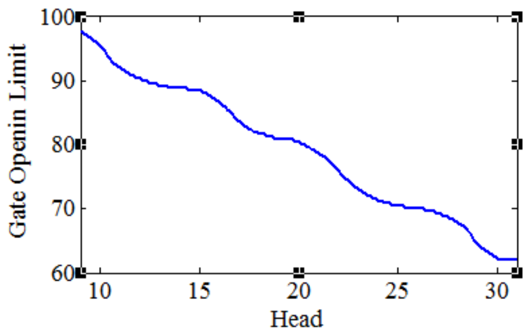

Figure 6c: Surface View of Triangular Shape MF & Bisector Defuzzification Method.

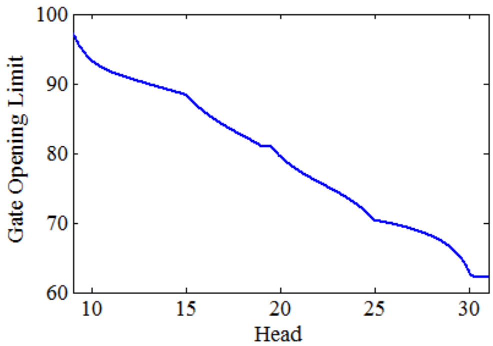

Figure 6d: Surface View of Triangular Shape MF & Centroid Defuzzification Method.

Simulation of Fuzzy Based Decision System

The overall fuzzy decision system for Gate opening limit has been simulated under the framework of MATLAB. The simulink model formed using Fuzzy Control (FC) blocks from Simulink tool of MATLAB is shown in fig.7. We have simulated all combinations of MFs and defuzzification methods for GL value. The FC-1 implements FIS that is built using bell shape MF and bisector defuzzification method. That of FC-2 implements FIS that is built using bell shape MF and centroid defuzzification method, FC-3 implements the fuzzy decision mechanism of FIS that is built using triangular shape MF and bisector defuzzification method, finally FC-4 implements FIS that is built using triangular shape MF and centroid defuzzification method,

In simulation a step random signal and a ramp signal in the range between 9 and 31 encircling the entire head values are applied one after another to the FC blocks as an input for the sudden change in value of Head and continuous change in value of Head. All FC blocks apply the inference rules on the input value of head and generate an output value that corresponds to the desired Gate opening limit for adequate discharge and generation. With change in the value of Head the corresponding change in Go value were observed with the use of scope and display blocks during the simulation study. These values of Gate opening Limit are compared with experts or experienced Operator's decision.

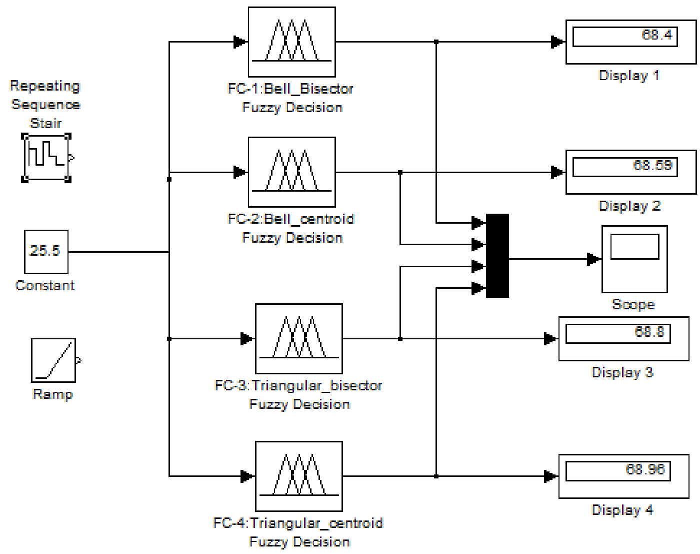

Figure 7: Fuzzy Based Decision System

Result and Discussion

Initially a sample value of 13.5 for Head input is applied to the fuzzy decision system. Based on this value, all designed FIS systems call upon the rules on the fuzzy value for 13.5 head input and compute value of the Gate opening limit (GL). The FIS designed by making use of bell shape MF and bisector defuzzification method (FC-1) gives the value of 87.6% for GL. The FIS designed using bell shape MF and centroid defuzzification method (FC-2) gives GL value of 89.26%. In the same way the FIS designed using triangular shape MF and bisector defuzzification method (FC-3) gives the output value of 88.8% for the GL. The GL value of 89.54% is given as decision output by FIS, which was designed using triangular shape MF and centroid defuzzification method (FC-4). Similarly we observed the output decision for the value GT of all FIS for the different Head input values. Based on the decision outputs, the FIS giving best optimal value of Gate opening limit for adequate discharge and generation is being selected. The trial simulation results of all FIS for Gate opening Limit value GL are presented in Table -4.

Table-4: Trial Result for FIS.

Head Available (meter)	FIS Gate opening Limit in %			
	FC-1	FC-2	FC-3	FC-4
10.6	95.2	94.15	93.2	92.27
15.9	86.4	85.17	86.8	86.14
19.9	78.4	78.29	80.4	79.82
23.6	70	71.58	72	73.49
27.8	65.6	65.81	68.4	68.32
30.2	61.6	63	62	62.29

To study graphical representation of the trial simulation results we applied a repeating stair case signal as Head input to FIS. Fig.8 depicts the decision of GL against random change in the Head. From the fig.8 and Table-4 we observed that fuzzy Gate opening limit settings for adequate discharge and generation given by FC-4 are in close agreement with experienced operator's settings.

To study the decision of designed FIS, a ramp signal in the range between 9 and 31 encompassing all the Head values was applied to the FC blocks as an input as shown in fig.9a. The output response for GL value decision of all FIS for the ramp input is shown in fig.9b. It is seen that from the proposed Fuzzy Decision Systems the FIS (FC-4) designed using bell shape MFs and employed centroid defuzzification method gives better result compared to other FIS. It gives the GL values for adequate discharge and generation for head inputs, which are near to or almost equal to an expert decision. From fig.9 it is observed that response of FIS that uses bell shape MFs and employed centroid defuzzification method (FC-2) for the ramp input is smoother as compared to other designed FIS systems FC-1, FC-3 and FC-4.

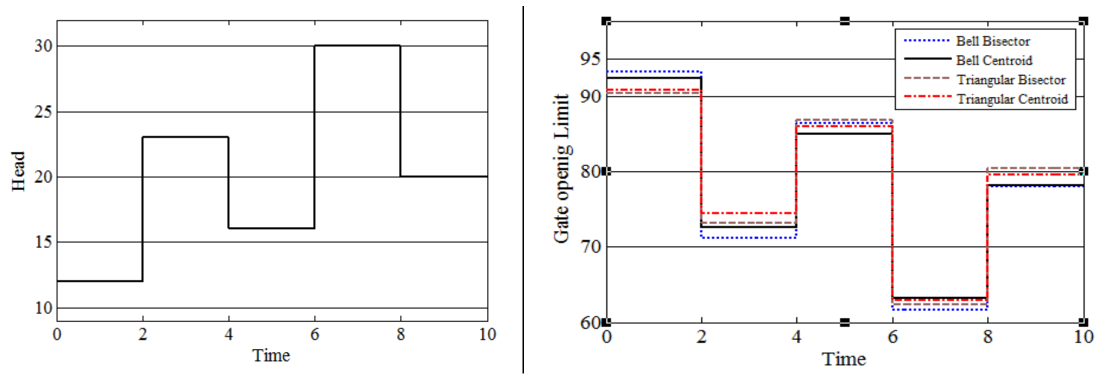

Figure. 8:-(a) Stair as Head Input to FIS (b) FIS Output Response of Different Combinations of MFs and Defuzzification Methods for Stair Input.

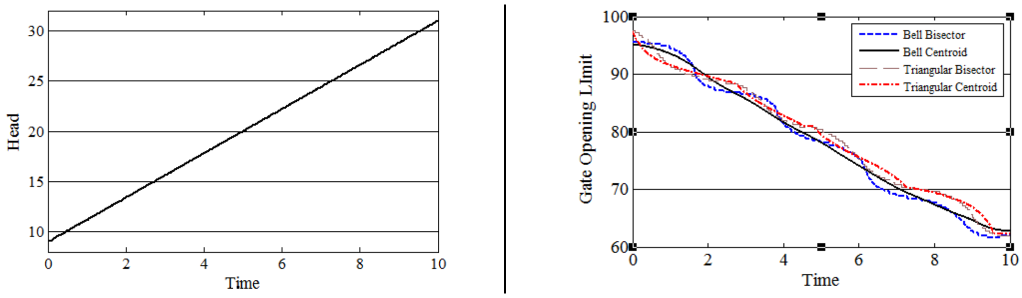

Figure.9. (a) Ramp as Head input to FIS (b) FIS Output Response of Different Combinations of MFs and Defuzzification Methods for Ramp Input.

Conclusion

The fuzzy logic decision system of Gate opening limit setting using small Numbers of rule has been implemented. The investigation of response of system reveals that the fuzzy decision system aimed to determine the optimal value of Gate opening for adequate discharge is smooth and robust. FLC has been used increasingly in industrial process control. Idea of employing Fuzzy Logic in Hydro Power Plant is novel. The very significance of proposing the incorporation of Fuzzy Logic in Hydro Power Plant Gate limiting Process is to implement system operator's knowledge to higher degree on the apparatus of fuzzy reasoning and make the automation process more humane. From the fig.8, fig.9 and results in Table-4 the FC-2 Gate opening limit settings are in close agreement with experienced operator's settings. However a good amount of time on elicitation of knowledge from operator followed by the vigorous tuning of FLC is inevitable for real time implementation.

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