Design and Development of Fuzzy Logic Controller for Liquid Flow Control

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Abstract- The purpose of this paper is to design a simulation system of fuzzy logic controller for Hydro-Electric Power Dam Control by using simulation package which is Fuzzy Logic Toolbox and Simulink in MATLAB software. By doing some modification of this paper, the design will be very useful for the system relates to liquid level control that widely use in industry nowadays. In this paper, we used the liquid level in tank , and use MATLAB to design a Fuzzy Control. The control of liquid level and flow between tanks is a basic problem in the process industries. Measuring the flow of liquids is a critical need in many industrial plants. Designers can realize lower development costs, superior features, and better end product performance by using fuzzy logic. Fuzzy Logic controller has better stability, small overshoot, and fast response. The paper presents Fuzzy Logic Controller (FLC) method for safe reservoir control of dams through spillway gates and it presents FLC method for turbine valve to control the water flow through turbine for hydro power generation. Thus it shows overall effective control and operation of the mechanical equipments in a hydro electric power generation project with FLC and its usefulness. Dam control system takes information about water level, gate opening ratios, gate operation as parameters and controls spillway in case of flooding. In this design two input parameters: water level and flow rate and two output parameters: release valve control and drain valve control are used.

Keywords –Fuzzy logic controller, Fuzzy logic Toolbox, Flow and Level Control, Valve Control, Simulink, System Model, Hydro-Eletric Power Plant

I. INTRODUCTION

Many of control technique very often face complex dynamic systems with nonlinear or time-variable behavior. This is the reason that the use of fuzzy logic took hold mainly in control engineering. FLC regulator has a very good result for complex nonlinear dynamic processes. Fuzzy logic control (FLC) can be applied for control of liquid flow and level in such processes. The fuzzy logic based modeling of a reservoir operation is a simple approach, which operates on an ’if-then’ principle, where ’if is a vector of fuzzy explanatory variables or premises such as the present reservoir pool elevation, the inflow, the demand, and time of the year. The ’then’ is a fuzzy consequence such as release from the reservoir. Power can be controlled by controlling flow through turbine and dams are maintained safely through controlling spillway gates. The control system keeps the reservoir water level in prescribed range. The nonlinearities occur in reservoir water level flow and these nonlinearities are unexpected. The aim of this fuzzy logic based control system is to adjust the dam lake level to the desired set points in the shortest time possible by adjusting the openness of spillway gates. The development of a hydro-electric power dam control system based on fuzzy logic with two inputs: water level and flow rate, and two outputs two output variables: Drain valve and Control valve used in a reservoir plant of Hydro-Electric Power Dam to monitor the system. To control the water release, the controller reads the water level and flow rate after every sampling period. But the level of water in the Dam must be controlled, and the flow between lakes must be regulated. These simulations in the fluid system with two tanks need a sensor to measure the water level and control it.

II. RELATED WORK

In[1], the author mentioned that an encode the fuzzy sets, fuzzy rules and procedures. The task is to design and display the simulation of the fuzzy logic controller for water level tank control and the result of the simulation will be display by using Rule Viewer which is part of the graphical user interface (GUI) tools in Fuzzy Logic Toolbox in MATLAB programmed. The simulation will display the animation of the water tank level that controlled based on the rules of fuzzy sets The purpose is to find the best way to get the result as close as the requirement for stability of the level control for the water tank. The author summarized the Fuzzy Logic Controller provides the accurate control of the liquid level in any industrial application.

In[2], the author described the coupled tank system that was supplied with a photovoltaic generator. The author also mentioned controlling variables in any process is very important so as to achieve the desired output .A nonlinear control of an induction motor (IM) supplied with a photovoltaic generator to assure the level control of two coupled tanks. Simulation results were given to highlight the performance of the proposed control method for load disturbances and parameter variation. The simulation results indicate that the proposed control schemes work very well and are robust to change in the parameters of the system as well as to disturbances acting on the global system.

In[3], the author have been done the comparative study of Fuzzy Logic controller and conventional PID controller for flowing fluids. In that paper, performance analysis of the conventional PI controller and fuzzy logic controller has been done by the use of Matlab and Simulink and in the end comparison of various time domain parameters is done to prove that the fuzzy logic controller has small overshoot and fast response as compared to PID controller. The author provided that the response of the PID controller is oscillatory which can damage the system. But the response of the fuzzy logic controller is free from these dangerous oscillations in the transient period. Hence, it is concluded that the conventional PID controller could not be used for the control of non-linear processes like fluid flows. So, the proposed fuzzy logic based controller design can be a preferable choice for that.

In[4], the author explained that fuzzy logic method is very useful for such problem solving approach such as small hydro power generation. The rule base and membership functions have a great influence on the performance and efficient of the plant. The present study intends to contribute for the improvement of fuzzy logic application through use of MATLAB FIS editor or manual calculations for hydro power generation.An efficient and accurate method based on fuzzy control is proposed for the hydro power generation and reservoir operating system in dams for safe and efficient performance. The author also mentioned that this work can be extended to develop a method for relating fuzzy logic-linguistic variables with various efficient control of other renewable energy generation in future.

In[5], the author designed that the construction of Hydro-Electric Power Dam Control System using Fuzzy Logic. In this design two input parameters: water level and flow rate and two output parameters: release valve control and drain valve control are used. This proposed system uses a simplified algorithmic design approach with wide range of input and output membership functions. The proposed simplified algorithmic design is verified using MATLAB simulation and results are found in agreement to the calculated values according to the Mamdani Model of the Fuzzy Logic Control System. Both the design model and simulation results are same. The designed system can be extended for any number of inputs and outputs. The drain valve control output can be utilized further for land irrigation according to the need and water release control valve for electric generation.

III.BASIC STRUCTURE OF THE PROPOSED HYDRO-ELECTRIC POWER DAM

Fig. 1 shows the main parts of the proposed hydro-electric power plant. Water in upper lake pass through the penstock. The water travel through a large pipe called penstock. Controllers are used to adjust dam lake level in set point only within shortest time by adjusting valve openness. Sensors are used to detect water level and flow rate. In this paper, ultrasonic sensors were selected. An ultrasonic sensor transmits ultrasonic waves into the air and detects reflected waves from an object. Water release control valve generates electricity. The force of water spins the turbine. Inside the generator, that creates an electric field and producing electricity. Water on releasing from the dam gets to the blades of the turbine all the way through the penstock. Its slope and thickness determines the efficiency of the dam. Required power related water level and flow rate. The greater the vertical distance between the upper and lower lakes, the more is the generation of electricity. Water flow out of the penstock flows into the lower lake. The drain valve control can be utilized further for land irrigation according to the need.

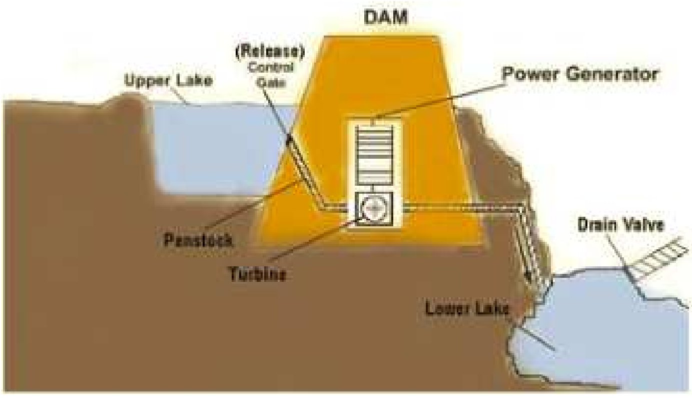


Figure.1: Arrangement of proposed hydro–electric power system

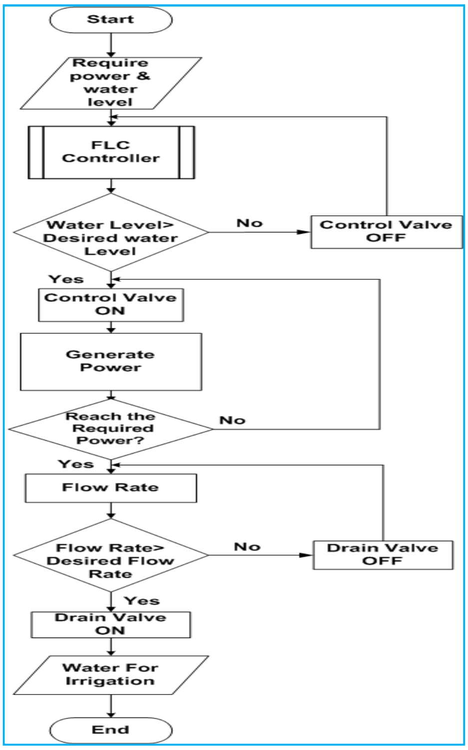
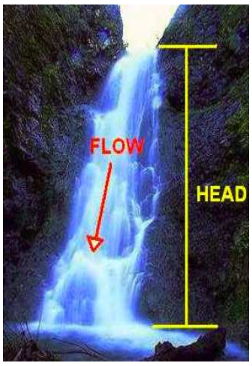


Figure.2: Flow chart of controller system



A. Output Power

The power available is proportional to the product of head and flow rate. The general formula for any hydro system’s power output is:

$$P=\eta\rho gQH$$

P=mechanical power produced at the turbine shaft (Watts)

η =hydraulic efficiency of the turbine
ρ=density of water (1000kg/m^3)
g=acceleration due to gravity (9.81m/s^2)
Q=volume flow rate passing through the turbine (m/s^3)
H=effective pressure head of water across the turbine (m)

B. Liquid Tank System

The parameters of the system are the parameters of the coupled tanks apparatus which is used to implement the proposed control schemes. It is important to understand the mathematics of how the coupled tanks system behaves. It is also important part of control systems analysis. A schematic diagram for single tank system is shown in figure 3.

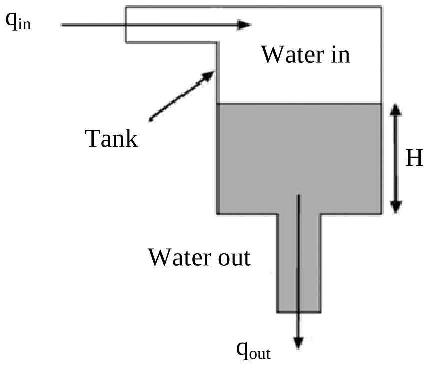


Figure.3: Schematic Diagram for the Liquid-Tank System

- Model Equations

The system model is determined by relating the flow q_{in} into the tank to the flow q_{out} leaving through the valve at the bottom tank. The rate of flow of water through the tank is according to Bernoulli Equation:

$$\frac{d}{dt}vol = \frac{Adh}{dt} = q_{in} - q_{out} = q_{in} - aC_d\sqrt{2gh}$$

A is cross-sectional area of the tank and h is the height of the liquid in the tank(m). In this equation a is the cross sectional area of the orifice (m).C_d is the discharge coefficient of the valve. g is gravitational constant (m/s^2).
This equation is derived from the general Bernoulli equation used to estimate flow through an underflow gate:

$$Q = a\,L\,C_q\sqrt{2gh}$$

Where: Q=discharge
C_q=discharge coefficient
a=gate opening
L=gate width
g=gravitational constant
h=level

C. Operation

This system was designed and displayed the simulation of the fuzzy logic controller for water level tank control and the result of the simulations were displayed by using Rule Viewer in Fuzzy Logic Tool box in MATLAB programmed. A controller for this system was taken the water error level (desired water level- actual water level) as an input and the rate at which the outlet valve is opening and closing as an output. Input of the controller applied a continuous square wave for creating continuous disturbance. Another input to the controller comes from feedback. The controller takes the action according to the error generated. This error and its derivative is applied to the controller which then takes the necessary action and decides the position of the valve which gives the desired flow of the liquid into the tank. The positioning of the valve is decided by the rules written in the Fuzzy Logic Controller Rule Editor. Water level in the schematic diagram which is driven by the simulink model changes with differing input in the rule viewer. For instant when the liquid level in the tank is above the set point and the rate is negative then the valve closed slowly.

IV. FUZZY LOGIC CONTROLLER

Fuzzy Logic Controller is an attractive choice when precise mathematical formulations are not possible . Other advantages are:

1. It can work with less precise inputs.
2. It doesn't need fast processors.
3. It needs less data storage in the form of membership functions and rules than conventional look up table for nonlinear controllers.
4. It is more robust than other non-linear controllers.

There are three principal elements to a fuzzy logic controller:

- a. Fuzzification module (Fuzzifier)
- b. Rule base and Inference engine
- c. Defuzzification module (Defuzzifier)

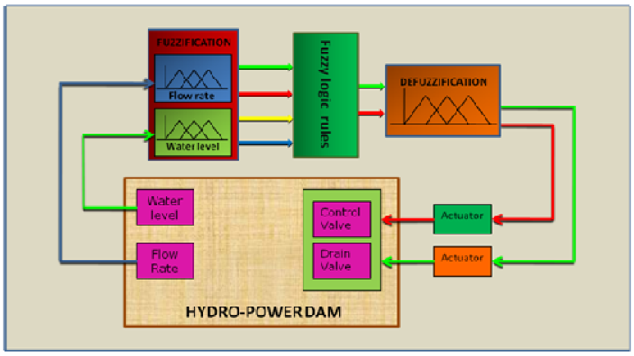


Figure.4: Block Diagram of Hydro-Electric Power Dam fuzzy control system

The algorithm designed for this system consists of two fuzzy input variables. Five triangular membership functions are equally determined over a scale range of -0.55m to 0.55m for the water level and $-0.2(m^3s^{-1})$ to $0.2(m^3s^{-1})$ for flow rate inputs. Two outputs of this proposed system are: (release) control valve and drainage valve. The control valves for release and drainage output variables consist of five membership functions: closed fast, closed slow, no change, opened slow, opened fast.

A. FIS Editor

Fuzzy Controller has two Inputs. One is Level of the liquid in the tank defined as "level" and the other one is rate of change of liquid in the tank denoted as "rate". Both these Inputs are applied to the Rule Editor. According to the Rules written in the Rule Editor the controller takes the action and governs the opening of the Valve which is the Output of the controller and are denoted by "control valve and drain valve". It may be shown as:

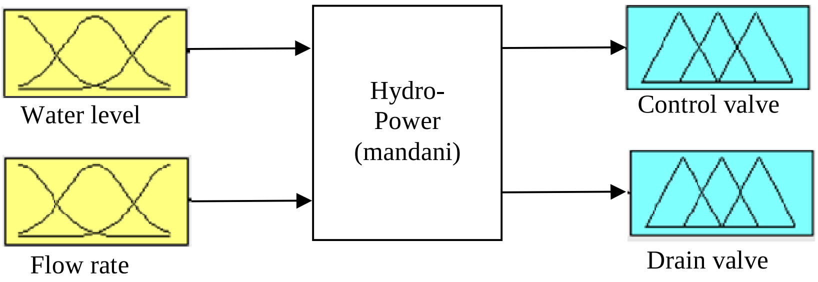


Figure.5: Mamdani type Fuzzy Controller

B. Membership Function Editor

- Fuzzy Set characterizing the Input:

Use triangular membership function types for the input. The five membership functions, “Above Danger”, “Danger”, “Below danger”, “Low” and “Very Low” are used to show the various ranges of input fuzzy variable “WATER LEVEL” in a plot consisting of four regions as shown in Fig.6.

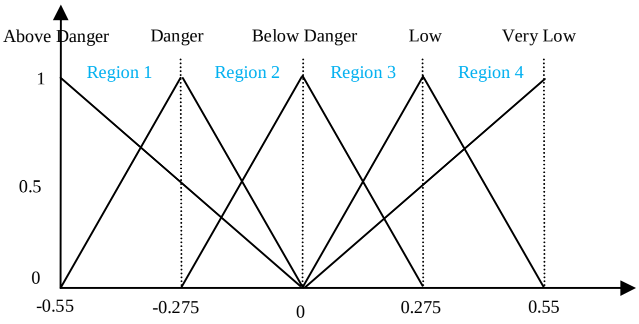


Figure.6: Membership Functions of Input Variable Water Level

The membership function has a triangular shape .The five membership functions, “Very Slow”, “Slow”, “Normal”, “Fast” and “Very Fast” are used to show the various ranges of input fuzzy variable “FLOW RATE” in a plot consisting of four regions as shown in Fig. 7.

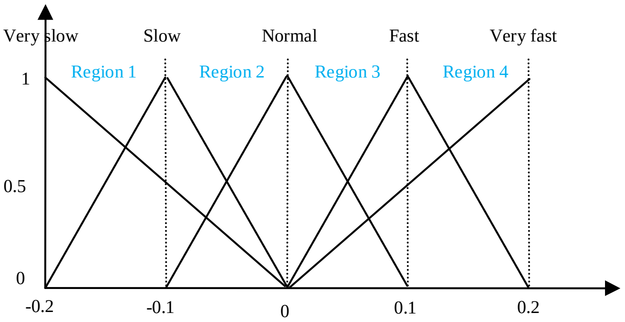


Figure.7: Membership Functions of Input Variable Flow Rate

- Fuzzy Set Characterizing the Output:

Use triangular membership function types for the output. First, set the range (and the Display Range) to (-20 20), to cover the output range. Initially, the *closed fast* membership function will have the parameters (-20 -18 -16), the *closed low* membership function will be (-12 -10 -8), for the *no change* membership function will be (-2 0 2), the opened slow membership function will be (4 6 8), the opened fast membership function will be (16 18 20).

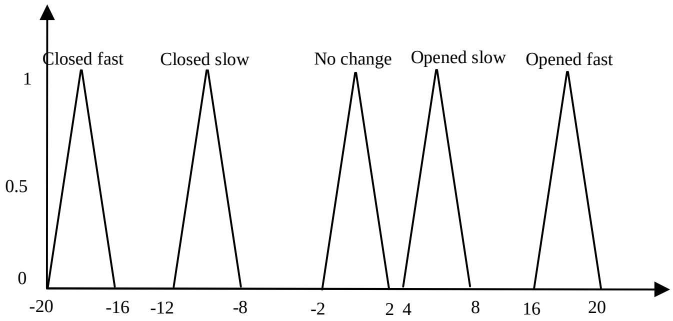


Figure.8: Triangular Membership Functions of Output Variable for Drain Valve & Control Valve

C. Fuzzy Rule

Number of active rules = $\mathbf{m^n}$

where m = maximum number of overlapped fuzzy sets and n= number of inputs.

For this design, m = 5 and n = 2, so the total number of active rules are 25.The total number of rules is equal to the product of number of functions accompanied by the input variables in their working range . The two input variables described here consisted of five membership functions. Thus, 5 x 5 = 25 rules were required which are shown in Table 1 and 2.

Table1:Total Number of Rules for Control Valve

Flow Rate Water level	Very Slow	Slow	Normal	Fast	Very Fast
Above Danger	Closed Fast	Closed Fast	Closed Fast	Closed Fast	Open Slow
Danger	Closed Fast	Closed Fast	Closed Fast	No Change	No Change
Below Danger	Open Slow	No Change	Closed Slow	Closed Slow	Closed Slow
Low	Opened Fast	Opened Fast	Opened Fast	Opened Fast	Opened Fast

Very Low	Opened Fast	Opened Fast	Opened Fast	Opened Fast	Opened Fast

Table2:Total Number of Rules for Drain Valve

Flow Rate Water level	Very Slow	Slow	Normal	Fast	Very Fast
Above Danger	Closed Fast	Closed Fast	Closed Fast	Open Slow	Open Slow
Danger	Open Slow	Open Slow	Open Slow	No Change	No Change
Below Danger	No Change	No Change	Closed Slow	Closed Slow	Opened Fast
Low	Opened Fast	Opened Fast	Opened Fast	Opened Fast	Opened Fast
Very Low	Opened Fast	Opened Fast	Opened Fast	Opened Fast	Opened Fast

D. Manual calculation for Control Valve and Drain Valve

Fuzzy conditions:

Definitions of Water Level (m) -Input(1): AD(-1.1 -0.55 0),D(-0.55 -0.275 0),BD(-0.275 0 0.275),L(0 0.275 0.55),VL(0 0.55 1.1)

Definitions of Flow rate (m3/sec) -Input(2):VS(-0.4 -0.2 0),S(-0.2 -0.1 0),N(-0.1 0 0.1),F(0 0.1 0.2),VF(0 0.2 0.4)

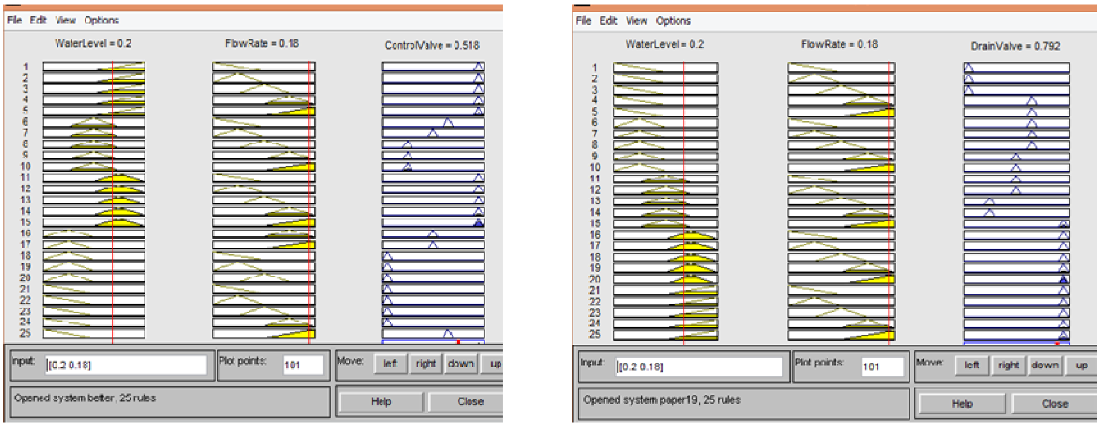
Now let us consider following condition:
Water Level (0.2m): BD (0.75) & L (0.25)
Flow rate (0.18m3/sec): F(0.4)&VF(0.6)
Strength of rule : [0.75^ 0.4] = 0.4
Strength of rule 5: [0.75 ^ 0.6] = 0.6
Strength of rule 7: [0.25 ^ 0.4] = 0.25
Strength of rule 8: [0.25 ^ 0.6] = 0.25 Now, C.O.G. = ∑μi*μ(i) /∑μi
Output for Control Valve: Hence, C.O.G. =
(0.4*0.25+0.6*0.25+0.25*1+0.25*1) / (0.4+0.6+0.25+0.25): C.O.G. = 50.0%– Output.
Output for Drain Valve: Hence, C.O.G. =
(0.4*0.25+0.6*1+0.25*1+0.25*1) / (0.4+0.6+0.25+0.25): C.O.G. = 80.0%– Output.

Rule Viewer

The Rule Viewer also shows how the shape of certain membership functions influences the overall result. Rules shown in Rule Editor provide inference mechanism strategy and producing the control signal as output.In this paper total number of active rules obtained is equal to 25 rules (= 5^2) as shown in Fig. The rules are based on “Mamdani Inference Method”. The simulation results are obtained using a 25 rule FLC. Rules shown in Rule Editor provide the control strategy.

A. *Response of Fuzzy Logic Controller using Rule Viewer*

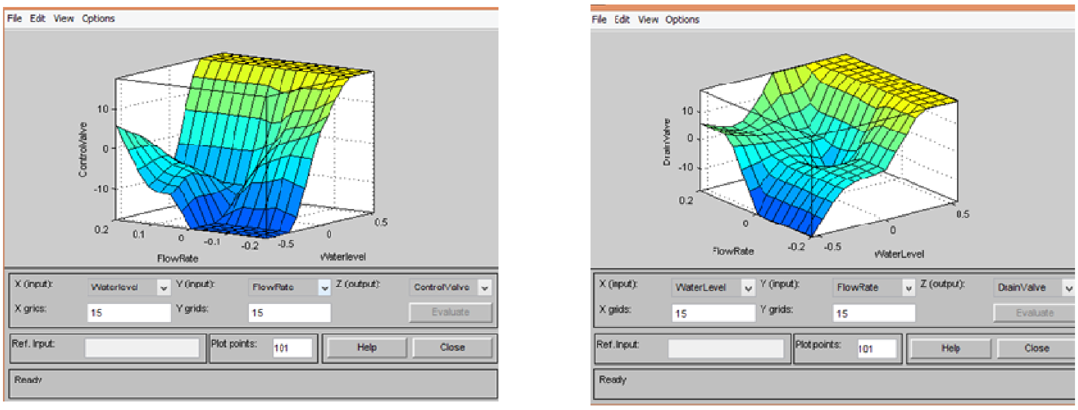
When the value of the level is 0.2 and the rate is 0.18 then the value of control valve and drain valve are 10.3 ,15.8 opened.



WaterLevel = 0.2
FlowRate = 0.18
ControlValve = 0.518
Input: [0.2 0.18]
Plot points: 101
Opened system better, 25 rules

WaterLevel = 0.2
FlowRate = 0.18
DrainValve = 0.792
Input: [0.2 0.18]
Plot points: 101
Opened system paper19, 25 rules

Figure.9:Fuzzy Logic Controller Using Rule Editor for Control Valve & Drain Valve



X (input): Waterlevel
Y (input): FlowRate
Z (output): ControlValve
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101
Ready

X (input): WaterLevel
Y (input): FlowRate
Z (output): DrainValve
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101
Ready

Figure.10:Fuzzy Logic Controller Using Rule Viewer for Control Valve & Drain Valve

V.SIMULATION TEST

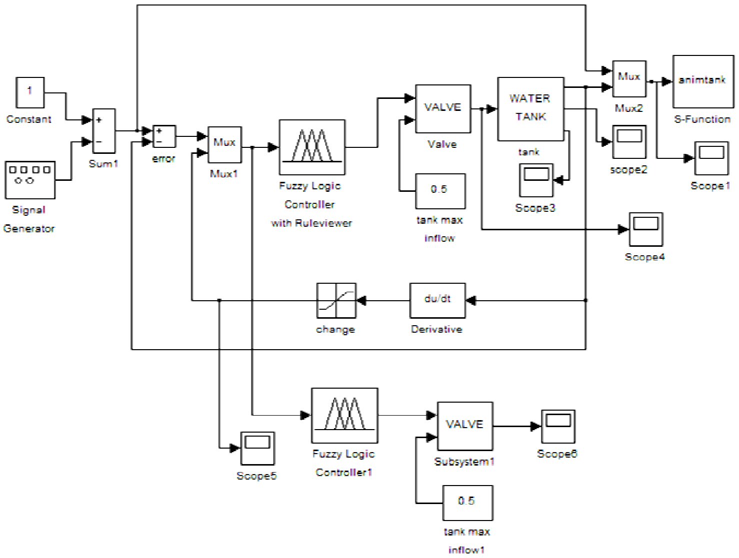


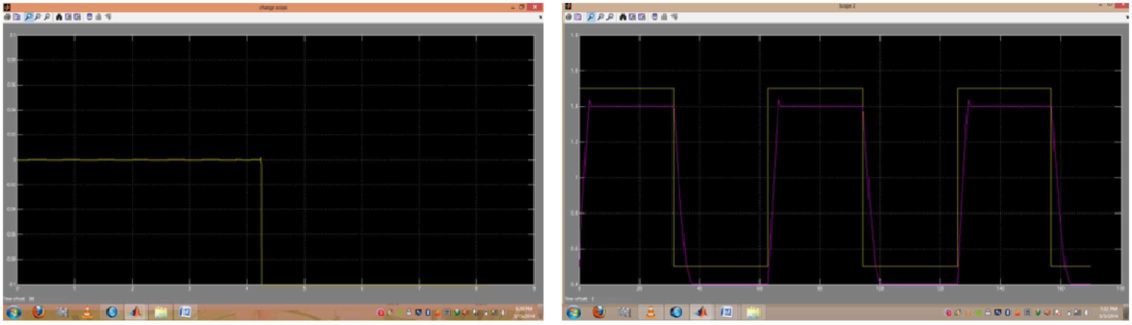
Figure.11:Simulink model by using Fuzzy Logic Controller

The controllers designed are simulated using the MATLAB/Simulink software. The parameters of the system are the parameters of the coupled tanks apparatus which is used to implement the proposed control schemes. A simulink model of Fuzzy Logic Controller for liquid level control:

VI. SIMULATION RESULTS

Different numbers of rules that used in the system will give the different result, so the analysis for results will be conducted. Besides that, this system will be also tested by using different types of methods and membership functions. It can be seen from these responses that the output converges to its desired value in all two cases. Therefore, it can be concluded that the proposed control schemes are robust to disturbances acting on the system and stabilizes the water levels to the desired level.

The figure shows the response of the fuzzy logic controller to the step input. Then the figure shows the input and output response simultaneously of the fuzzy logic controller. Yellow line shows the input and pink line shows the output. Figure shows the performance response of Fuzzy logic controller respectively.



(a) (b)

Figure.12: (a)Performance for Fuzzy Logic Controller (b) Simulation Result Using Fuzzy Logic Controller

VII. CONCLUSION

In this paper, reservoir of water in dam is controlled by efficiently and accurately. The result shows that fuzzy logic controller is useful in applications of nonlinear static characteristic, and is allows the user apply their knowledge of the problem and transfer it to an appropriate system environment, which is close to the human way of thinking (liquid level tank control). The FLC on a level control problem with promising results can be applied to an entirely different industrial level controlling apparatus. For the optimization of the membership function simulation evolution algorithm is used. The fuzzy logic based control, optimized by simulation algorithm provides effective and accurate alternative for human operator.

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