

LIQUID LEVEL CONTROL BY USING FUZZY LOGIC CONTROLLER

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ABSTRACT

Fuzzy Logic is a paradigm for an alternative design methodology, which can be applied in developing both linear and non-linear systems for embedded control. By using fuzzy logic, designers can realize lower development costs, superior features, and better end product performance..In control systems there are a number of generic systems and methods which are encountered in all areas of industry and technology. From the dozens of ways to control any system, it turns out that fuzzy is often the very best way. The only reasons are faster and cheaper. One of successful application that used fuzzy control is liquid tank level control. The purpose of this project is to design a simulation system of fuzzy logic controller for liquid tank level control by using simulation package which is Fuzzy Logic Toolbox and Simulink in MATLAB software. By doing some modification of this project, the design will be very useful for the system relates to liquid level control that widely use in industry nowadays. For a long time, the choice and definition of the parameters of PID are very difficult. There must be a bad effect if that you do not choose nicely parameters. To strictly limit the overshoot, using Fuzzy Control can achieve great control effect. In this paper, we take the liquid level water tank , and use MATLAB to design a Fuzzy Control. Then we analyze the control effect and compare it with the effect of PID controller. As a result of comparing, Fuzzy Control is superior to PID control. Especially it can give more attention to various parameters, such as the time of response, the error of steadying and overshoot. Comparison of the control results from these two systems indicated that the fuzzy logic controller significantly reduced overshoot and steady state error. The fuzzy logic controller used in this study was designed with Lab VIEW(R) a product of National Instruments Corporation. Lab VIEW(R) is an icon-based graphical programming tool with front panel user interfaces for control and data visualization and block diagrams for programming.

KEYWORDS: PID, FLC, Rule Viewer, FIS, GUI

I. LIQUID LEVEL CONTROLLER

1.1 Introduction

While modern control theory has made modest inroad into practice, fuzzy Logic control has been rapidly gaining popularity among practicing engineers. This increased popularity can be attributed to the fact that fuzzy logic provides a powerful vehicle that allows engineers to incorporate human reasoning in the control algorithm. As opposed to the modern control theory, fuzzy logic design is not based on the mathematical model of the process. The controller designed using fuzzy logic implements human reasoning that has been programmed into fuzzy logic language (membership functions, rules and the rules interpretation)It is interesting to note that the success of fuzzy logic control is largely due to the awareness to its many industrial applications. Industrial interests in fuzzy

logic control as evidenced by the many publications on the subject in the control literature has created an awareness of its interesting importance by the academic community[1]. Starting in the early 90s, the Applied Research Control Lab at Cleveland State University supported by industry partners, initiated a research program investigating the role of fuzzy logic in industrial control. The primary question at that time was: “What the fuzzy logic control does that the conventional cannot do?” Here we concentrate on fuzzy logic control (one of the Intelligent Control Technique) as an alternative control strategy to the current proportional – integral – derivative (PID) method widely used in industry[2]. Consider a generic liquid level control application shown in figure :

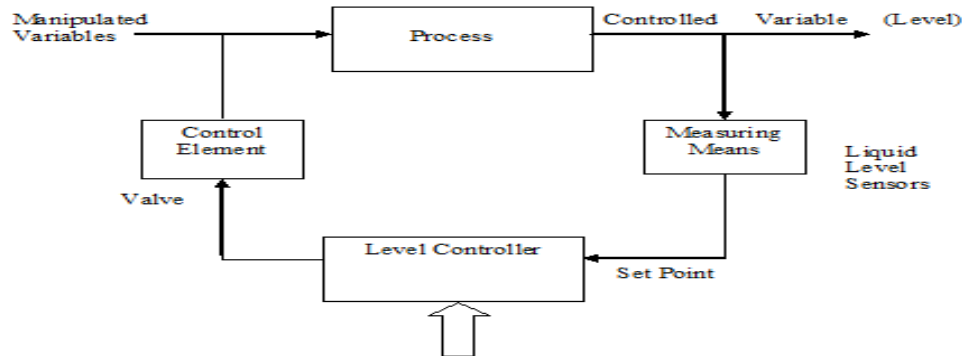


Figure.1:- A typical industrial Liquid Level control Problem

1.2 Liquid-Tank System

Water enters a tank from the top and leaves through an orifice in its base. The rate that water enters is proportional to the voltage, V , applied to the pump. The rate that water leaves is proportional to the square root of the height of water in the tank.

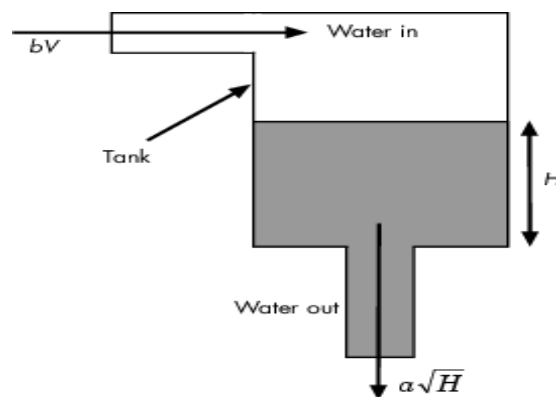


Figure.2:- Schematic Diagram for the Liquid-Tank System

1.3 Model Equations

A differential equation for the height of liquid in the tank, H , is given by

$$\frac{d}{dt} Vol = A \frac{dH}{dt} = bV - a\sqrt{H}$$

where Vol is the volume of liquid in the tank, A is the cross-sectional area of the tank, b is a constant related to the flow rate into the tank, and a is a constant related to the flow rate out of the tank. The equation describes the height of liquid, H , as a function of time, due to the difference between flow rates into and out of the tank. The equation contains one state, H , one input, V , and one output, H . It is nonlinear due to its dependence on the square-root of H . Linearizing the model, using Simulink Control Design, simplifies the analysis of this model[3]. The level is sensed by a suitable sensor and converted to a signal acceptable to the controller. The controller compares the level signal to the

desired set-point temperature and actuates the control element. The control element alters the manipulated variable to change position of the valve so that the quantity of liquid being added can be controlled in the process. The objective of the controller is to regulate the level as close to the set point as possible.

1.4 Liquid Level Sensors

There are many types of liquid level sensors available in the market. Some of these are:

1.4.1 Single-Point Control

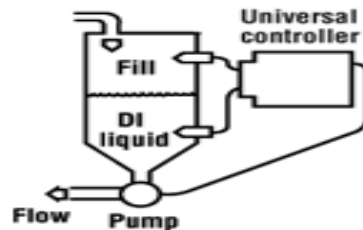


Figure.3:- Single-point control

A) **Common application:** Keep tank from overflowing or running dry.

B) **Compatible sensor types:** Float, capacitance, optical, proximity, tuning fork, ultrasonic

C) **How it works:** Each time the liquid reaches a critical level, the sensor turns on a pump or opens a valve to prevent the tank from overflowing/running dry.

1.4.2 Dual-Point Control

A) **Common application:** Keep tank filled between two critical points.

B) **Compatible sensor types:** Same as for single-point control (above).

C) **How it works:** Install sensors at two critical points. If liquid falls below the lower sensor, the detector activates a pump until liquid reaches the upper sensor.

1.4.3 Triple-Point Control

A) **Common application:** Keep tank filled between three critical points.

B) **Compatible sensor types:** Same as for single-point control (above).

C) **How it works:** Install sensors at two critical points. If liquid falls below the lower sensor, the detector activates a pump until liquid reaches the upper sensor.

1.4.4 Continuous level control

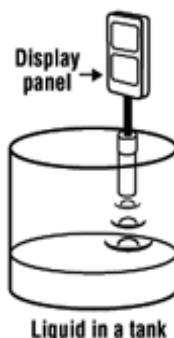


Figure.4:- Continuous-level control

A) **Common application:** Control level at all points and times, possibly activating a pump, valve, or alarm.

B) **Compatible sensor types:** Symprobe™, Cricket™, ultrasonic, radar wave

C) How it works: Continuous-level sensors have a continuous analog output that is proportional to the level at all times. Level may be recorded with an external device.

1.4.5 Animtank

This block shows the animation of the tank at different instants. The program for this is written in animtank.m file which is being used in the subsystem as a s-function.

1.5 Working:

A continuous square wave is applied at the I/P to the controller for creating continuous disturbance. Another I/P 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 PID Controller or by the rules written in the Fuzzy Logic Controller Rule Editor. If the liquid level in the tank is low then the valve open completely and if the liquid level is high in the tank then the valve closes or opens upto an extent. When the level is full then the valve closes completely. The designing of the PID controller can be changed by changing the values of Proportional Gain, Integral Gain & Derivative Gain and the effect of the changed values can be seen effectively using Rule Viewer. The designing of the Fuzzy Logic Controller is covered as a separate topic and is explained in the next section.

1.6 Applications

1.6.1 Classification of Liquid Level Controllers:

There are several types of level controllers. Some of these are:

A) Level Controllers: Level controllers are devices that operate automatically to regulate liquid or dry material level values. There are three basic types of control functions that level controllers can use, limit control, linear control and advanced or nonlinear control [4].

B) Integrated motion controllers: Integrated motion control systems contain matched components such as controllers, motor drives, motors, encoders, user interfaces and software. The manufacturer optimally matches components in these systems. They are frequently customized for specific applications.

C) Pump Controllers: Pump controllers manage pump flow and pressure output.

D) Flow controllers: Flow controllers allow metered flow of fluid in one or both directions. Many of them allow for free flow in one direction and reduced or metered flow in the reverse direction.

1.6.2 Industrial Uses: We consider level control a fundamental control technique [5]. Level controls are used in all types of applications:

- Tank farms
- Boilers
- Waste treatment Plants
- Reactors

II. DESIGNING OF FUZZY LOGIC CONTROLLER

2.1 The FIS Editor

We have defined two Inputs for the Fuzzy Controller. One is Level of the liquid in the Tank denoted 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 [6]. 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 is denoted by “valve”. It may be shown as:

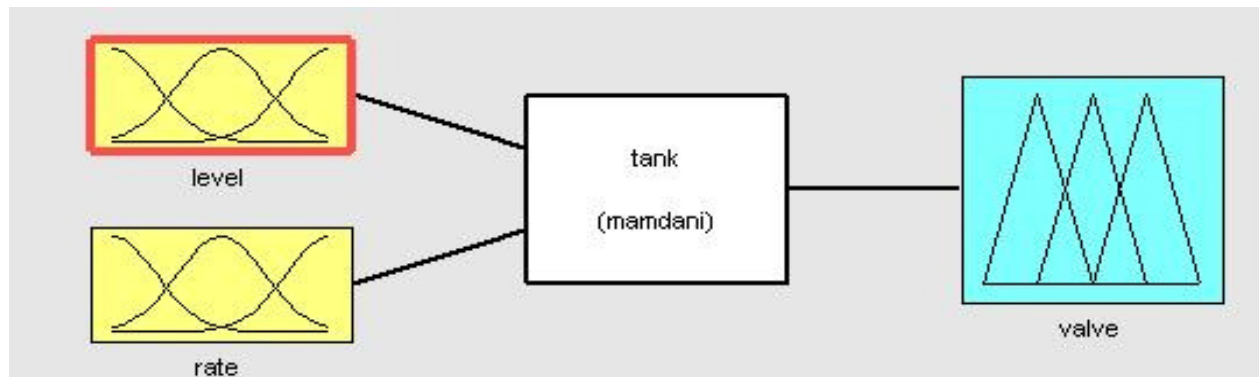


Figure.5:- Mamdani type Fuzzy Controller

2.2 The Membership Function Editor

The Membership Function Editor shares some features with the FIS Editor. In fact, all of the five basic GUI tools have similar menu options, status lines, and **Help** and **Close** buttons. The Membership Function Editor is the tool that lets you display and edit all of the membership functions associated with all of the input and output variables for the entire fuzzy inference system[7-8]. When you open the Membership Function Editor to work on a fuzzy inference system that does not already exist in the workspace, there are not yet any membership functions associated with the variables that you have just defined with the FIS Editor.

2.2.1 Fuzzy Set characterizing the Input

A) level	(Range: -1 to 1)	
Fuzzy Variable	MF used	Crisp Input Range
High	Gaussian MF	(0.3,-1)
Ok	Gaussian MF	(0.3,0)
Low	Gaussian MF	(0.3,1)

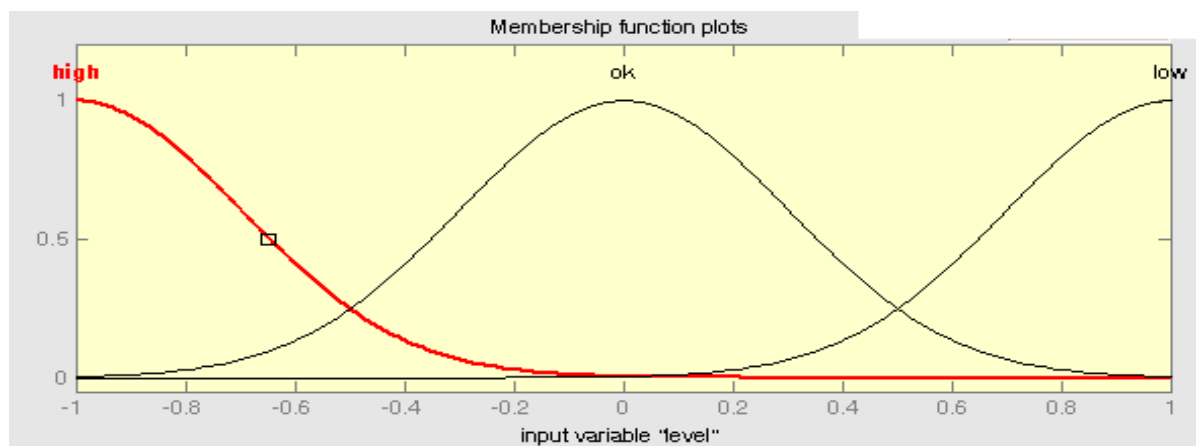


Figure.6:-Membership function Fuzzy Set characterizing the Input

B) rate	(Range: -1 to 1)	
Fuzzy Variable	MF used	Crisp Input Range
Negative	Gaussian MF	(.03,-0.1)
Zero	Gaussian MF	(.03,0)
Positive	Gaussian MF	(.03,0.1)

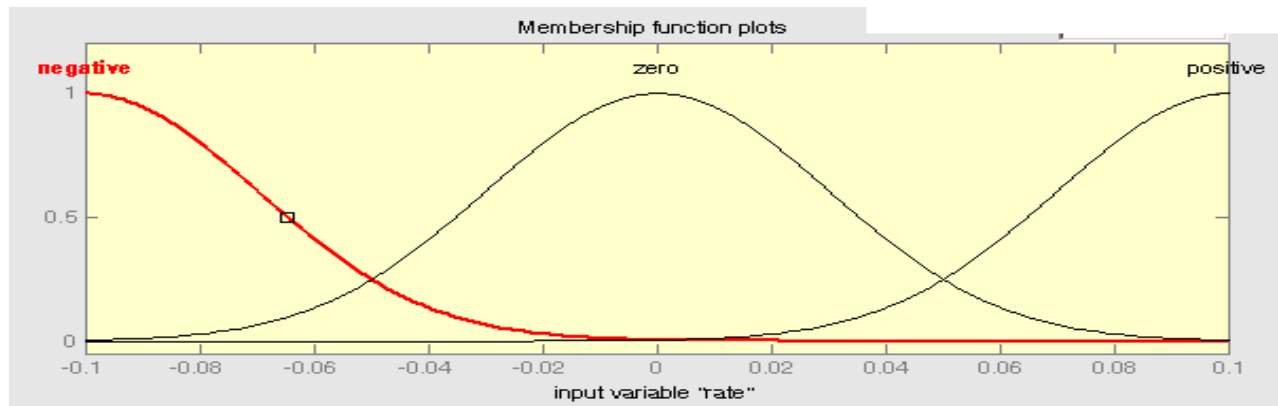


Figure.7:-Membership function Fuzzy Set Characterizing the Output

2.2.2 Fuzzy Set Characterizing the Output:

Use triangular membership function types for the output. First, set the Range (and the Display Range) to (-1 1), to cover the output range. Initially, the *close fast* membership function will have the parameters (-1.0 -0.9 -0.8), the *close low* membership function will be (-0.6 -0.5 -0.4), for the *no change* membership function will be (-0.1 0 0.1), the open slow membership function will be (0.2 0.3 0.4), the open fast membership function will be (0.8 0.9 1.0). Your system should look something like this.

A) valve	(Range: -1 to 1)	
Fuzzy Variable	MF used	Crisp Input Range
Close_fast	Triangular MF	(-1.0 -0.9 -0.8)
Close_low	Triangular MF	(-0.6 -0.5 -0.4)
No_change	Triangular MF	(-0.1 0 0.1)
Open_slow	Triangular MF	(0.2 0.3 0.4)
Open_fast	Triangular MF	(0.8 0.9 1.0)

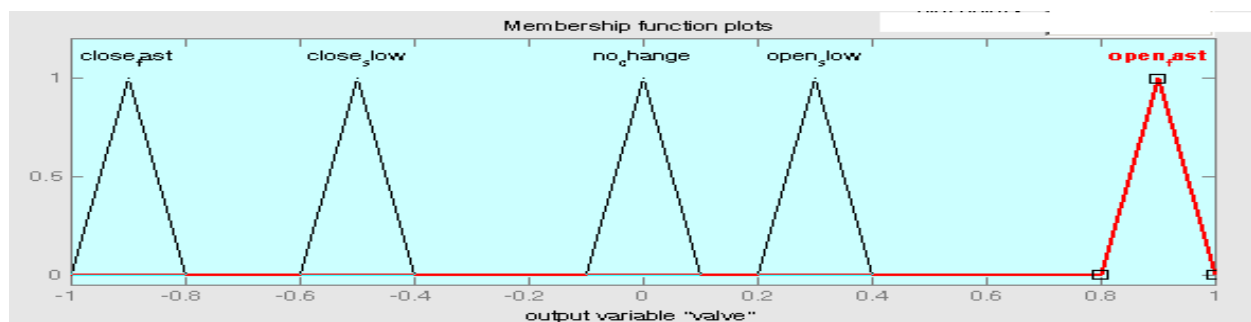


Figure.8:- Triangular membership function output

2.2.3 The Rule Editor:

Constructing rules using the graphical Rule Editor interface is fairly self-evident. Based on the descriptions of the input and output variables defined with the FIS Editor, the Rule Editor allows you to construct the rule statements automatically, by clicking on and selecting one item in each input variable box, one item in each output box, and one connection item[9]. Choosing none as one of the variable qualities will exclude that variable from a given rule.

1. if (level is ok) then (valve is no_change) (1)
2. if (level is low) then (valve is open_fast) (1)
3. if (level is high) then (valve is closed_fast) (1)
4. if (level is ok) and (rate is positive) then (valve is close_slow) (1)
5. if (level is ok) and (rate is negative) then (valve is open_slow) (1)

The water tank model consists of

- The water-tank system itself
- A Controller subsystem to control the height of water in the tank by varying the voltage applied to the pump
- A reference signal that sets the desired water level
- A Scope block that displays the height of water as a function of time

Double-click a block to view its contents. The Controller block contains a simple proportional-integral-derivative controller[10]. The Water-Tank System block is shown in this figure.

2.3.4 Water-Tank System Block

The circuitry for the water tank system may be shown as:

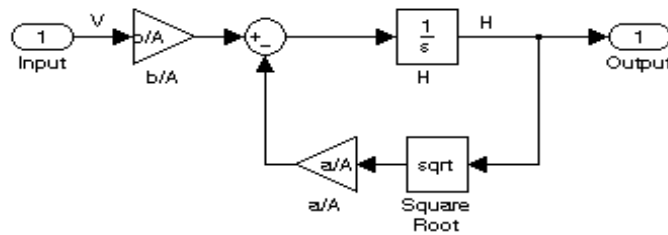


Figure.12:- Block diagram of water tank system

Model equation for the Water-Tank System Block may be shown as:

$$\frac{d}{dt} Vol = A \frac{dH}{dt} = bV - a\sqrt{H}$$

where Vol is the volume of water in the tank, A is the cross-sectional area of the tank, b is a constant related to the flow rate into the tank, and a is a constant related to the flow rate out of the tank. The equation describes the height of water, H , as a function of time, due to the difference between flow rates into and out of the tank. Values of the parameters are given as $a=2 \text{ cm}^{2.5}/\text{s}$, $A=20 \text{ cm}^2$, $b=5 \text{ cm}^3/(\text{s}\cdot\text{V})$.

2.3.5 Controller block

The circuitry for the controller of water tank may be shown as:

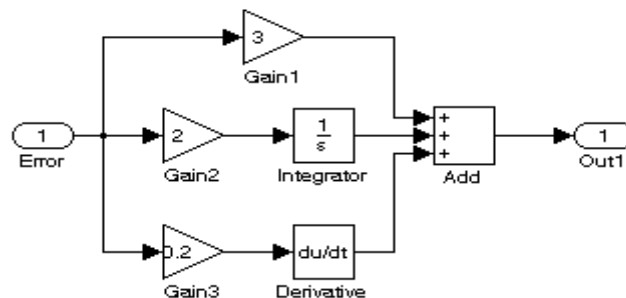


Figure.13:- Block diagram of controller

For the Fuzzy Controller there are two Inputs. One is the liquid level and the other is the rate of change of liquid level in the tank[11-13]. The output of the controller governs the opening or closing of the valve. The liquid level is sensed by the liquid level sensors and the rate of change is calculated by the derivative of the level signal after that the limits of which are decided by a saturation non-linearity.

III. SIMULATION RESULTS & DISCUSSION

3.1 Simulink model for PID controller

A simulink model for Conventional (PID) Controller for liquid level control

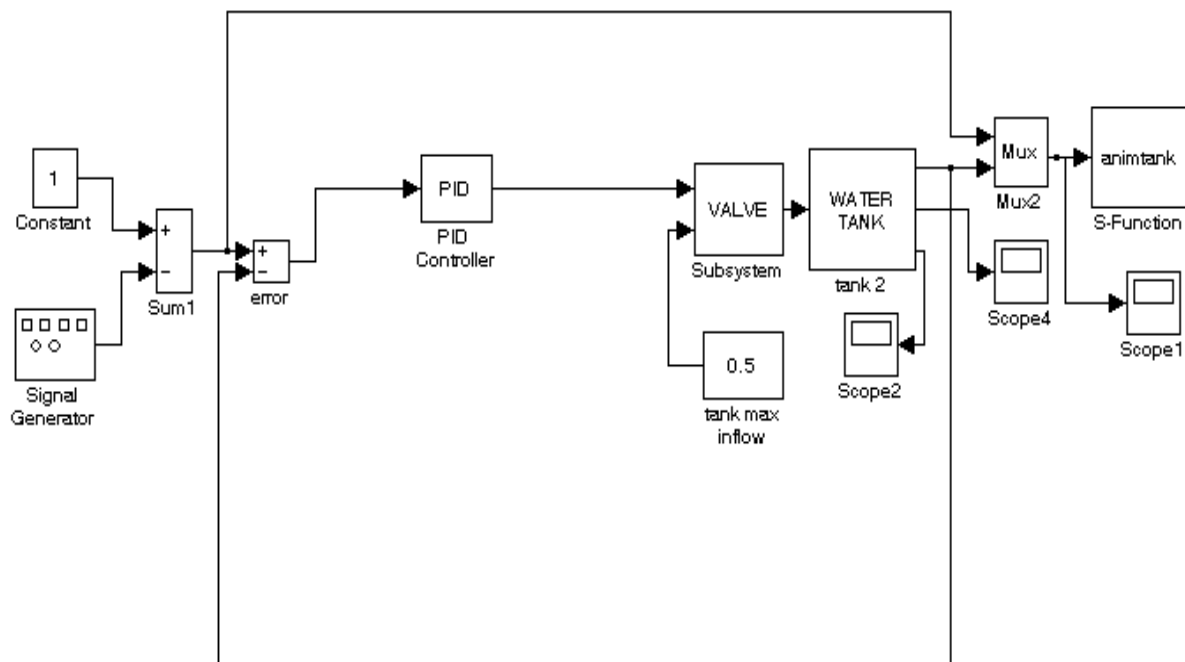


Figure.14:- Simulink model by using PID controller

3.1.1 Simulation Results

Response of Liquid Level Controller using PID Controller:

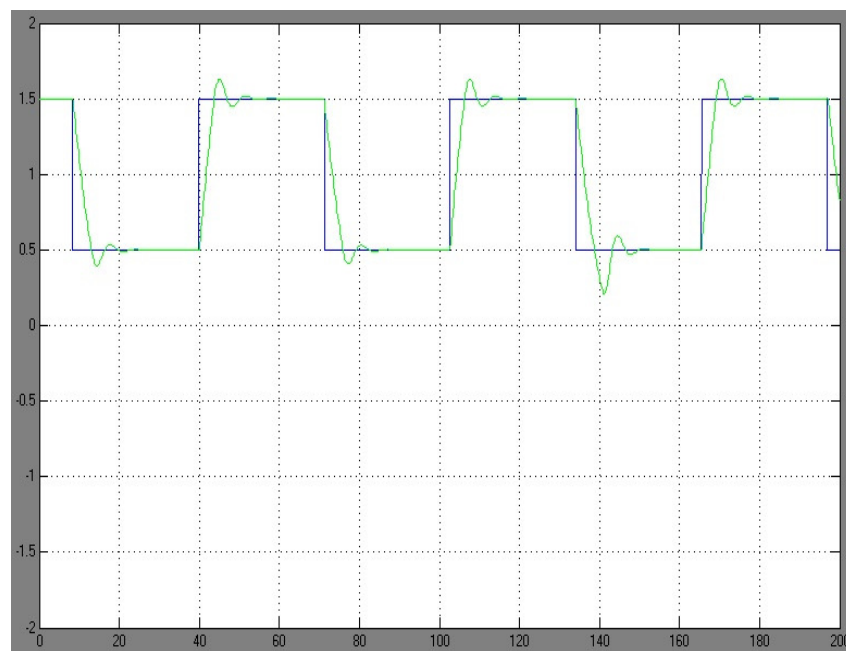


Figure.15:- Simulation result using PID controller

From fig. 15 it is seen that PID controllers drives the system unstable due to mismatch error generated by the inaccurate time delay parameter used in the plant model. Transients & overshoots are present when PID controller is used to control the liquid level.

3.2 Simulink model for fuzzy logic controller

A simulink model for For Fuzzy Logic Controller for liquid level control

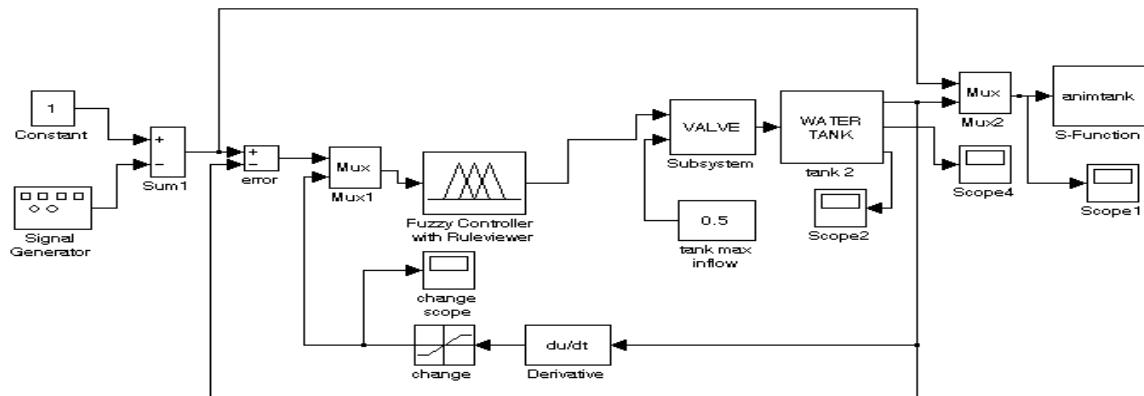


Figure.16:- Simulink model by using fuzzy logic controller

3.2.1 The Rule Viewer:-

The Rule Viewer allows you to interpret the entire fuzzy inference process at once. The Rule Viewer also shows how the shape of certain membership functions influences the overall result. Since it plots every part of every rule, it can become unwieldy for particularly large systems, but, for a relatively small number of inputs and outputs, it performs well (depending on how much screen space you devote to it) with up to 30 rules and as many as 6 or 7 variables[14]. The Rule Viewer shows one calculation at a time and in great detail. In this sense, it presents a sort of micro view of the fuzzy inference system. If you want to see the entire output surface of your system, that is, the entire span of the output set based on the entire span of the input set, you need to open up the Surface Viewer.

3.2.2 Response of Fuzzy Logic Controller using Rule Viewer

When the value of the level is 0.349 and the rate is -0.04 then the value of valve is 0.176.

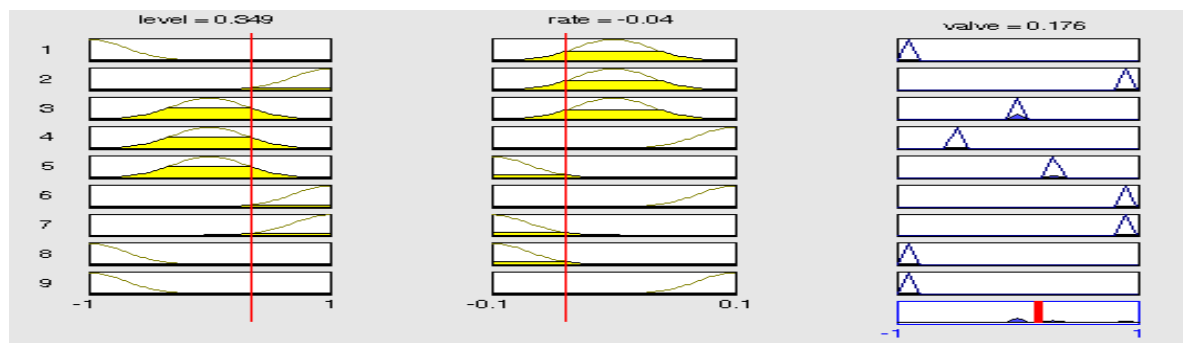


Figure.17:- Fuzzy Logic Controller using Rule Viewer

When the value of the level is -0.6 and the rate is 0.06 then the value of valve is -0.741.

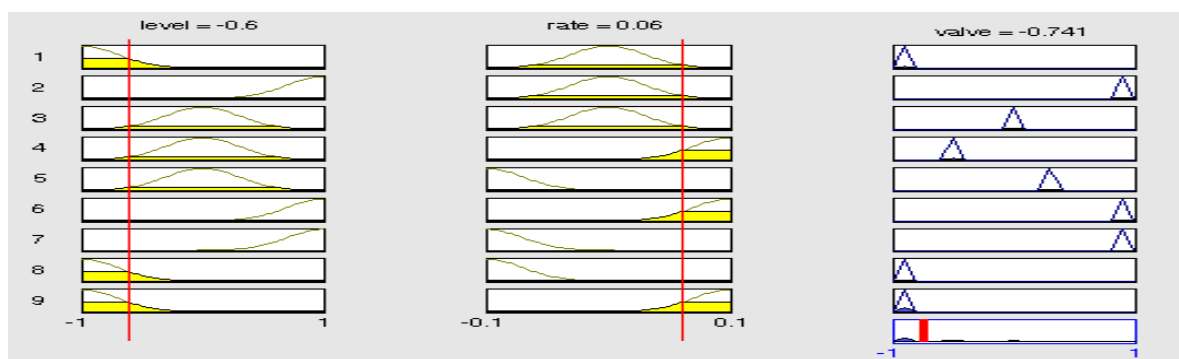


Figure.18:- Fuzzy Logic Controller using Rule Viewer

3.2.3 Simulation Results

Response of Liquid Level Controller using Fuzzy Logic Controller

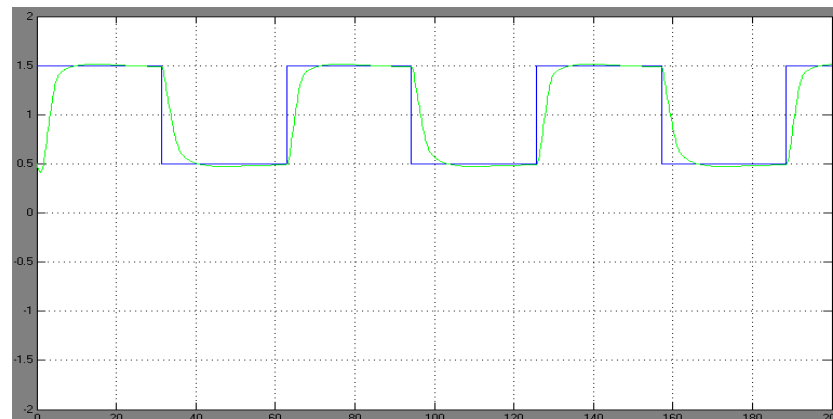


Figure.19:- Simulation result using Fuzzy Logic controller

From fig. 19 FLC provide good performance in terms of oscillations and overshoot in the absence of a prediction mechanism. The FLC algorithm adapts quickly to longer time delays and provides a stable Response.

IV. DISCUSSION

The FLC is applied to the plant described above in figure 16. Obtained FLC simulation results are plotted against with that of conventional controller PID controller for comparison purposes. The simulation results are obtained using a 9 rule FLC. Rules shown in Rule Editor provide the control strategy. Here these rules are implemented to the above control system. For comparison purposes, simulation plots include a conventional PID controller, and the fuzzy algorithm. As expected, FLC provide good performance in terms of oscillations and overshoot in the absence of a prediction mechanism. The FLC algorithm adapts quickly to longer time delays and provides a stable response while the PID controllers drives the system unstable due to mismatch error generated by the inaccurate time delay parameter used in the plant model. From the simulations, in the presence of unknown or possibly varying time delay, the proposed FLC shows a significant improvement in maintaining performance and preserving stability over standard PID method.

To strictly limit the overshoot, using Fuzzy Control can achieve great control effect. In this paper, we take the liquid level water tank, and use MATLAB to design a Fuzzy Control. Then we analyze the control effect and compare it with the effect of PID controller. As a result of comparing, Fuzzy Control is superior to PID control. Especially it can give more attention to various parameters, such as the time of response, the error of steadying and overshoot. Comparison of the control results from these two systems indicated that the fuzzy logic controller significantly reduced overshoot and steady state error.

Comparison results of PID and FLC are shown above.

The overall performance may be summarized as:

Parameter	PID	FLC
Overshoot	Present	Not Present
Settling Time	More	Less
Transient	Present	Not Present
Rise Time	Less	More

V. CONCLUSION

Unlike some fuzzy controllers with hundreds, or even thousands, of rules running on dedicated computer systems, a unique FLC using a small number of rules and straightforward implementation is proposed to solve a class of level control problems with unknown dynamics or variable time delays commonly found in industry. Additionally, the FLC can be easily programmed into many currently

available industrial process controllers. The FLC simulated on a level control problem with promising results can be applied to an entirely different industrial level controlling apparatus. The result shows significant improvement in maintaining performance over the widely used PID design method in terms of oscillations produced and overshoot. As seen from the graphs drawn in figures 48 and 49, the rise time in case of PID controller is less but oscillations produced and overshoot and settling time is more. But in case of fuzzy logic controller, oscillations and overshoot and settling time are low, so FLC can be applied where oscillations can not be tolerated in the process. The FLC also exhibits robust performance for plants with significant variation in dynamics.

Here FLC and PID both are applied to the same exactly modelled level control system and simulation results are obtained. Had these techniques been applied to a system whose exact system dynamics were not known, PID wouldn't have taken care of the unknown dynamics or variable time delays in the system.

Fuzzy Logic provides a completely different, unorthodox way to approach a control problem. This method focuses on what the system should do rather than trying to understand how it works. One can concentrate on solving the problem rather trying to model the system mathematically, if that is even possible. This almost invariably leads to quicker, cheaper solutions.

VI. FUTURE WORK

The scope of project is to encode the fuzzy sets, fuzzy rules and procedures. Then perform fuzzy inference into the expert system (Fuzzy Logic Toolbox). 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. This project is designed to make use of the great advantages of the Fuzzy Logic Toolbox and integrate it with SIMULINK which is also in MATLAB programmed. The Fuzzy Logic Toolbox has the ability to take fuzzy systems directly into Simulink and test them out in a simulation environment. The simulation will display the animation of the water tank level that controlled based on the rules of fuzzy sets. This project covers the processes of developing the application of fuzzy expert system in water tank level control. It starts from the theory until it implemented into the simulation environment. In addition, this project also makes the analysis of the variety results that obtained from system. 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. 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 Fuzzy Logic Controller provides the accurate control of the liquid level in any industrial application.

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