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Design of Fuzzy Controller for Flow Control Applications

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Abstract: Flow control is important in many industrial applications such as chemical reactor, heat exchanger. The objective is to overcome the problems inherited with the conventional PID control scheme such as handling undeterminable disturbance, immeasurable noise and further improve the transient state and steady state response performance. The proposed control scheme is implemented in Flow Control and to Calibration of Pilot Plant. The design is done using MATLAB software package and controller can directly connected to the Pilot Plant through by USB-type DAQ cards. Simulation and implementation results will gives the developed controller has less overshoot, better control performance, disturbance handling ability, great lustiness and it is more flexible and spontaneous to tune.

Key words: Flow Control · Controller design · Pilot Plant

INTRODUCTION

A flow control valve regulates the flow or pressure of a fluid. Control valves normally respond to signals generated by independent devices such as flow meters or temperature gauges. Control valves are normally fitted with actuators and positioners. Pneumatically-actuated globe valves and Diaphragm Valves are widely used for control purposes in many industries, although quarter-turn types such as ball, gate and butterfly valves are also used. Control valves can also work with hydraulic actuators (also known as hydraulic pilots). These types of valves are also known as Automatic Control Valves. The hydraulic actuators will respond to changes of pressure or flow and will open or close the valve. Automatic Control Valves do not require an external power source because fluid pressure is enough to open and close the valve. Automatic control valves include pressure reducing valves, flow control valves, back-pressure sustaining valves, altitude valves and relief valves. To reduce the effect of these load disturbances, sensors and transmitters Collect information about the process variable and its relationship to some desired set point. When all the measuring, comparing and calculating the process. Final control element must implement the strategy selected by the controller. The most common final control element in the process control industries is the control valve. The control valve manipulates a flowing fluid (such as gas, steam, water, or chemical compounds) to compensate for the load disturbance and keep the regulated process variable as close as possible to the desired set point.

PID Controller: In general PID controller is the combination of P-proportional, I-integral, D-derivative controllers. The values of these three parameters are interpreted in terms of time, where, 'P' depends on the present error, 'I' on the accumulation of past errors and 'D' is a prediction of future errors, based on current rate of change. By tuning the three parameters, PID controller can provide control action designed for specific process requirements. The proportional, integral and derivative terms are summed to calculate the output of the PID controller equation and final output [1] defined by u (t) and it given (1) by

$$u(t)=k_p\, e(t) + k_i \int_0^t e(t)dt + k_d \left(\frac{de(t)}{dt}\right) \tag{1}$$

Most of the industrial processes are pneumatic valve with PID controller. In industrial PID controller contain box, not an algorithm, Auto-tuning functionality of both pre-tune and self-tune, Manual or cascade mode switch, Bump less transfer between different modes, set point

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ramp, Loop alarms, Networked or serial port would give a simple model design of PID controller. Model-based tuning is Look at the closed-loop poles and Numerical optimization of the performance index over the PID controller. Basically PID controllers are used in Cohen coon method or Zeigler-Nichols method for tuning purpose.

Ziegler–Nichols Method: Ziegler-Nichols proposed rules for determining the values of the proportional gain K_p, integral time K_i and derivative time K_d based on the transient –response characteristics of a given plant. PID controller is implemented in plant and it can be transfer function to oscillate and then stabilize of output. In the Ziegler-Nichols method is used in plant and it can be neither integrators nor dominant complex conjugate poles. The conventional PID controller gives some overshoot, large amount of settling time and rise time. But in Ziegler Nichols method the overshoot is completely eliminated but rises time and settling time is greater than the conventional PID. In general, Ziegler Nichols methods have provided starting point and tuning is necessary to get the appropriate value. After tuning of the PID controller both the rise time and settling time will be reduced in large amount and there is some overshoot but anyway it is very less compare to conventional PID controller. Ziegler-Nichols method table is shown in Table.1

Table 1: Ziegler Nichols Method

Control Type	K_p	K_i	K_d
P	0.5 *K_u	-	-
PI	0.45*K_u	1.2*K_p/T_u	-
PID	0.60*K_u	2*K_p/T_u	K_p*T_u/8

The response of the PID controller can be described in terms of the responsiveness of the controller to an error, the degree to which the PID controller overshoots the set point and the degree of system oscillation. It should be noted that the use of the PID algorithm for control and it guarantee optimal control of the system or system stability. The Conventional PID controller and its output to a step input response as achieved with some particular control parameter values. PID Controller is used in the areas like mechanical, hydraulic, pneumatic techniques. Basically controller is a device. Recently PID controller is used in form of software package like MATLAB. Typical applications of controllers are used to hold settings for temperature, pressure, flow or speed. A system can either be described as a multiple inputs and multiple outputs system (MIMO). MIMO system is requiring more than one controller. In case of single input and single output (SISO) system, it is required only a single controller. Depending on the set-up of the physical (or non-physical) system, adjusting the system input variable will affect the operating parameter; otherwise, it is taken as the controlled output variable. Upon receiving the error signal that marks the disparity between the desired value (set point) and the actual output value, the controller will then attempt to regulate controlled output behavior. The controller achieves by either attenuating or amplifying the input signal to the plant so that the output is returned to the set point.

Fuzzy Logic Controller: The input variables in a fuzzy control system are general mapped by sets of membership functions known as "fuzzy sets". The process of converting a crisp input value to a fuzzy value or linguistic variables is called "fuzzification". Defuzzification interface converts the fuzzy output into crisp number using membership functions [2]. Rule base is a set of IF-THEN statements that represent experts linguistic knowledge while decision-making unit converts Fuzzy inputs to Fuzzy outputs using the Rule Base and rules activation to determine and combined using operators such as AND, OR and NOT operators. Number of fuzzy rules is an important issue in fuzzy controller design, especially for real time applications. For control applications, often there is no enough data for a designer to create the rule base for the fuzzy controller. A general rule base includes all possible combinations of fuzzy input values. The size of fuzzy rule base grows exponentially as the number of controller input grows. A complete rule base for the fuzzy controller with n inputs and m membership functions per input will result in mn rules. Therefore the rule base reduction is very important for the fuzzy controller in the control applications. Basic configuration of fuzzy logic controller is shown in the Figure 1.

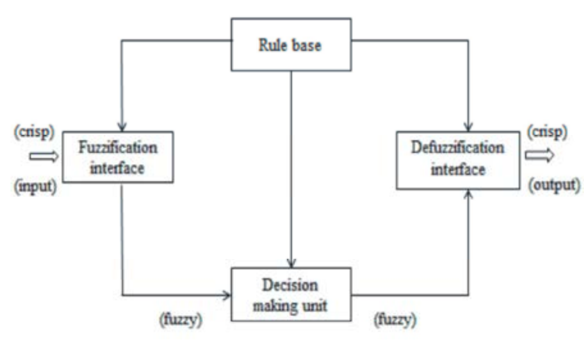

Fig. 1: Basic Configuration of Fuzzy Logic System

Membership Function: There are various types of membership function to assign input variable [3]. Choose Gaussian type as a fuzzy output membership function. The two input are assigned in the form of E(error) and CE(change in error). Selecting the language variables for two input "E", "CE" is choosing seven fuzzy values (NB, NM, NS, ZO, PS, PM, PB) is the set of linguistic values which respectively represent "negative big", "negative medium", "negative small", "zero", "positive small", "positive medium" and "Positive big". Error and Change of Error have Gaussian-type MFs and universe of discourses are set to [-30 30]. The input and membership function is shown in the Figure. 3a, Figure. 3b and Figure. 2 with respectively.

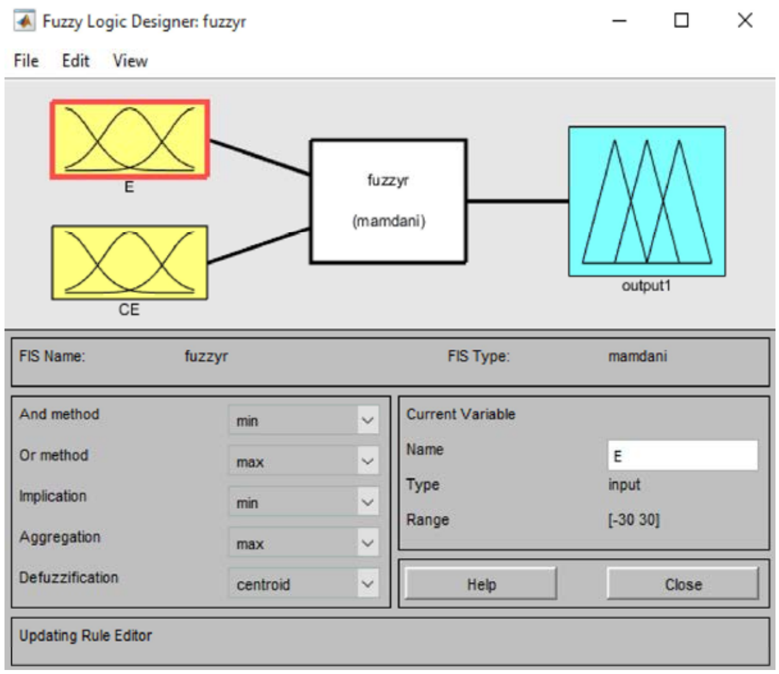

Fig. 2: Membership Function

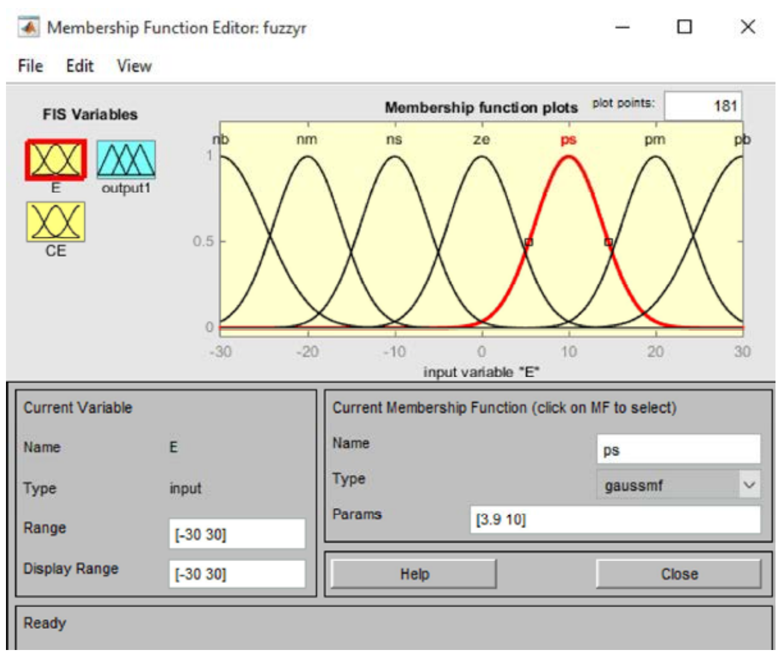

Fig. 3a: Input1 Membership Function

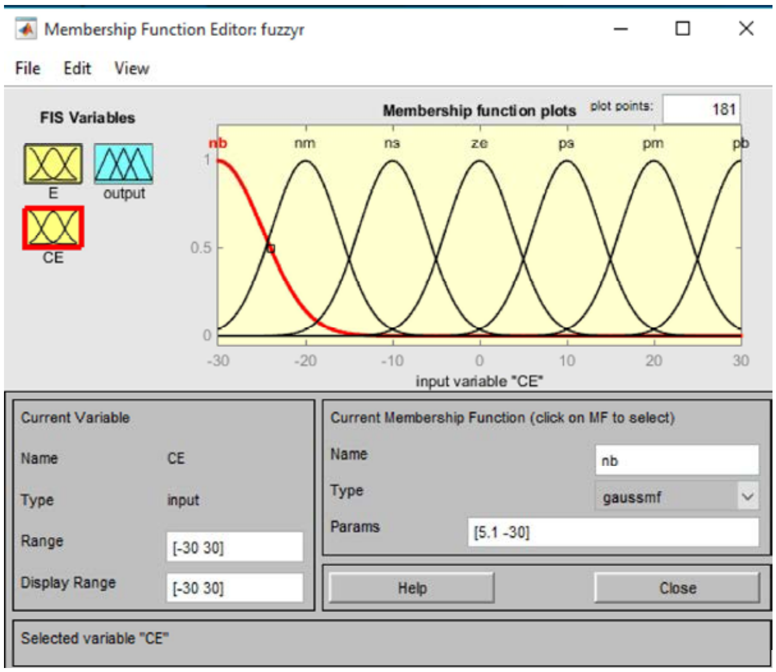

Fig. 3b: Input2 Membership Function

There are various types of membership function to assign output variable. Choose Gaussian type as a fuzzy output membership function and it described output to assign seven fuzzy values (NB, NM, NS, ZO, PS, PM, PB). Here (NB, NM, NS, ZO, PS, PM, PB) is the set of linguistic values which respectively represent "negative big", "negative medium", "negative small", "zero", "positive small", "positive medium" and "positive big". The output membership functions for the output are discrete values rather than fuzzy membership functions. All outputs are distributed equally in the range of [-0.4, 0.4] and membership function of output is shown in Figure 4.

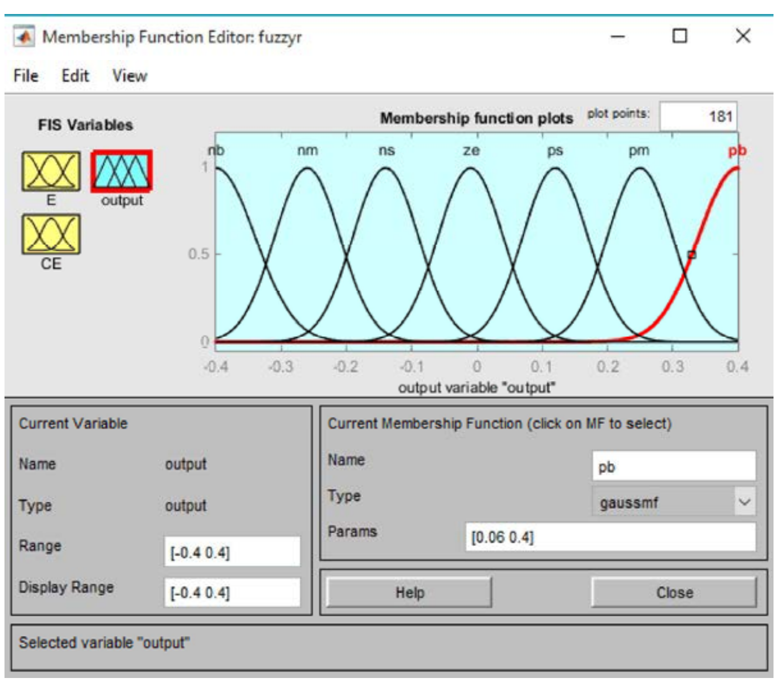

Fig. 4: Output Membership Function

Fuzzy Rules: The rules are assigned according to both the input E(error) and CE(change in error) with respect to output. Rule viewer shows assigned input and output values. Fuzzy logic is widely used in machine control. The term "fuzzy" refers to the fact that the logic involved and it can deal with concepts "partially true" but it cannot be expressed as the "true" or "false". Fuzzy logic as an advantage that the solution of the problem can be cast in terms those human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanics tasks and already it is successfully performed by humans. The Fuzzy Logic Controller with Rule viewer block implements a fuzzy inference system (FIS) with the Rule Viewer in Simulink. Rule Viewer for the fuzzy inference system, fuzzyr. It is used to view the entire implication process from beginning to end. Rule viewer can move around the line indices that correspond to the inputs and then watch the system readjust and compute the new output. All the rules are assigning to rule base editor is shown in Figure 5. The File menu for the Rule Viewer is the same as the one found on the FIS Editor. Surface viewer shows 2-D format allocation. This format can be rule base and it can appear menu like Verbose, Symbolic, or Indexed. Rule viewer and surface viewer is shown in Figure 6. and Figure 7 with respectively.

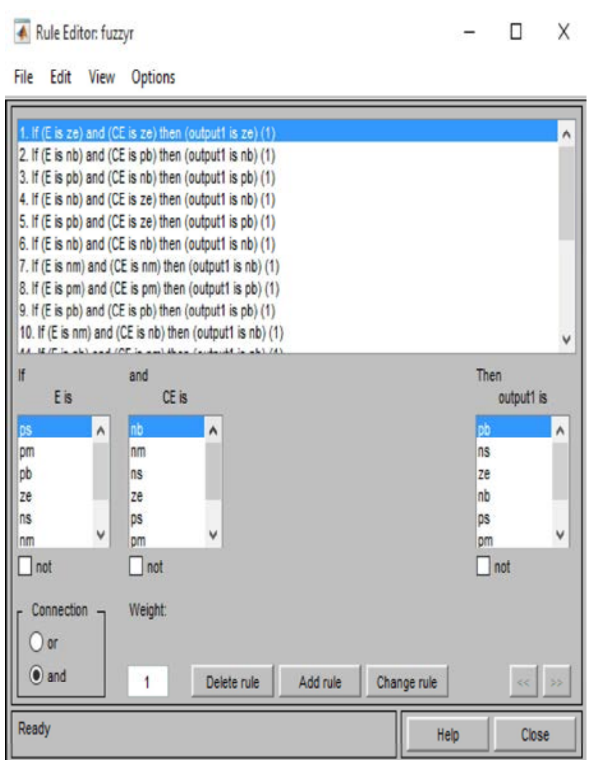

Fig. 5: Rule Base Editor

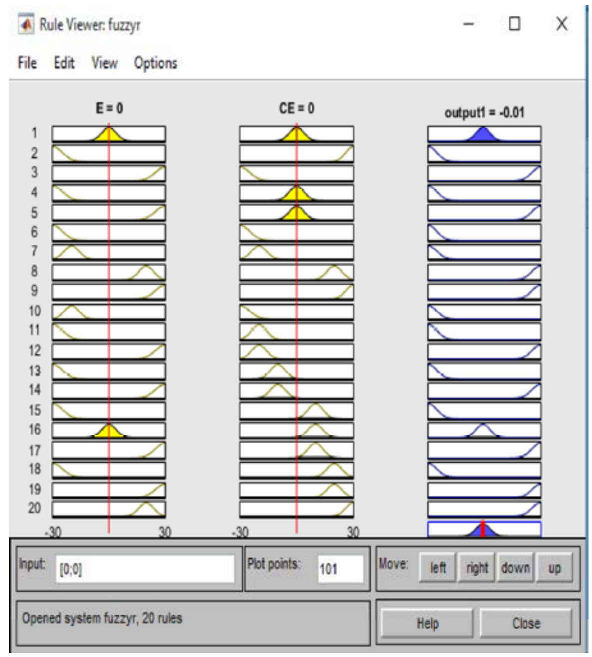

Fig. 6: Rule viewer

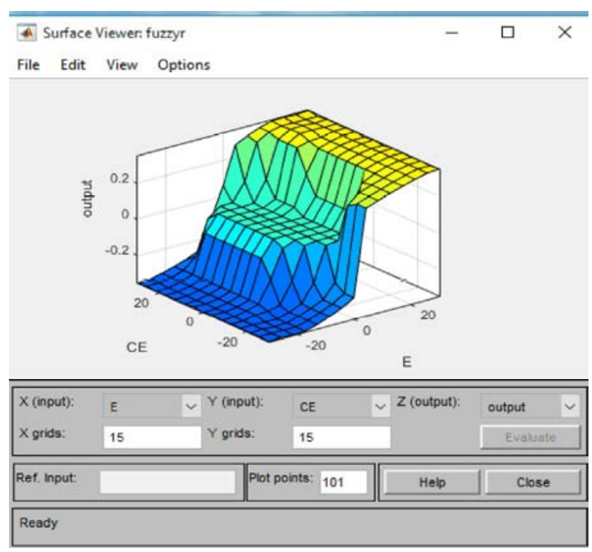

Fig. 7: Surface Viewer

Experimental Setup Diagram: Controller techniques are directly connected to the plant through Daq card and the matlab software is used to control the entire plant [4]. Data from Pilot Plant are in 4-20mA and converted to 1-5V using series 250 Ohm resistors. Data acquisition is the process of sampling signals and it measures real world physical conditions.so that it converts the resulting samples into digital numeric values that can be manipulated by a computer [5]. Set up is shown in Figure 8.

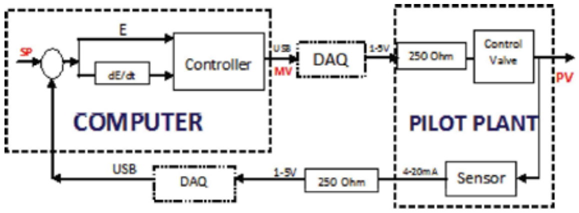

Fig. 8: Setup Diagram

Pilot Plant Setup: The Pilot plant is simply two series tanks with the transferring the fluid from Buffer Tank to Calibration Tank. The fluid flow rate is control by two tanks. Two pumps are used to circulate the fluid by valve into the two tanks. Computer controls the flow rate by controlling the opening of the Control Valve and measurements are obtained via Coriolis flow transmitter. The plant is composed by two water tanks, T1 and T2, interconnected via a system of pipes enabling liquid flow to the tanks. The flow from T1 to T2 occurs by gravity, since T2 is positioned above T1, through a valve R1. The flow from T1 to T2 requires the action of a centrifugal pump to raise the liquid level, through a valve R2.pilot plant setup diagram is shown in Figure 9.

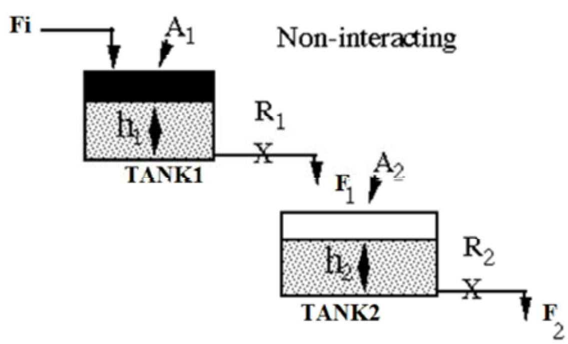

Fig. 9: Pilot Plant Setup Diagram

RESULT AND DISCUSSION

The simulation of PID and fuzzy logic controller (2) are based on FODT model in equation [6].

$$G(s) = \frac{Ke^{-\tau d^{s}}}{\tau g+1} \quad (2)$$

The result of empirical modelling of pilot plant (3) is in form of FODT.

$$G(s) = \frac{0.7e^{-0.63s}}{0.17s+1} \quad (3)$$

Simulation of PID Controller: The output of PID controller simulation result obtained with the help of MATLAB. Simulation of PID [7] controller has step input with transfer function as well as tuning of PID controller gives output in steady state performance with some oscillations and it can be directly measured by water tank is shown in Figure 10.

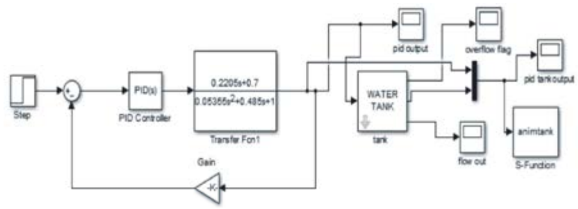

Fig. 10: Simulation of PID controller

Output of PID Controller: The output of PID controller has minimum overshoot and fastest response is required. A PID controller has been used for industrial purpose due to their simplicity, easy designing method, low cost and effectiveness. In conventional PID controller contains some overshoot but steady state control performance [8] at the output is shown in Figure 11.

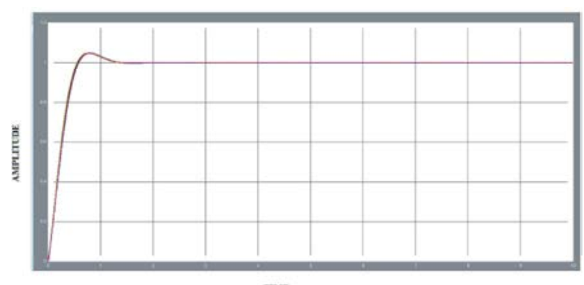

Fig. 11: Output of PID controller

Simulation of Fuzzy Logic Controller: Simulation of fuzzy logic controller has step input with fuzzy membership function. The input variables in a fuzzy control system are general mapped by sets of membership functions known as "fuzzy sets". Fuzzy output is controlled by linear membership function and eliminate of error as well as future scope error is shown in the figure.12

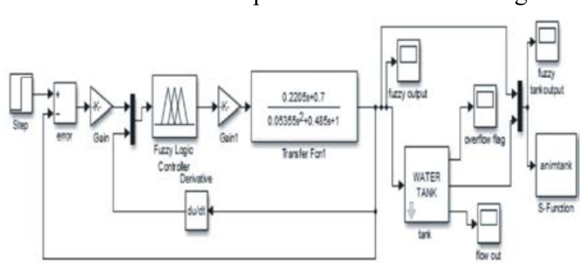

Fig. 12: Simulation of Fuzzy Logic controller

Output of Fuzzy Logic Controller: Output of fuzzy logic controller gives linear constant value. Fuzzy controller is the forward path in a feedback control system. Fuzzy Logic Controller can perform well despite presence of process nonlinearities, operation variability and measurements noise. As a result of fuzzy logic controller is shown in the Figure 13.

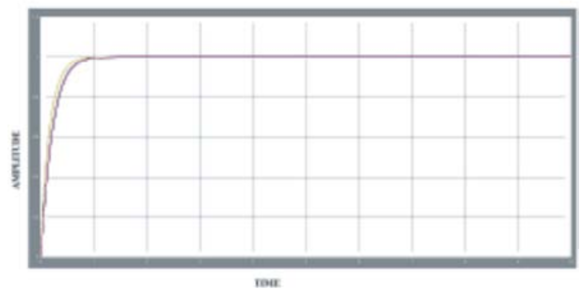

Fig. 13: Output of Fuzzy logic controller

Table 2: Response Charactertics for Controllers

Mode Charactertics	Simulation Pid Controller	Fuzzy Logic Controller
Rise Time	0.403	0.374
Settling Time	1.04	0.666
Peak Time	0.806	1.4
Peak Amplitude	1.03	1.0
Peak Overshoot (%)	3.3	0
Steady State	1.0	1.0

CONCLUSION

Controller has various types such as PID, Fuzzy Logic and some of the intelligent controllers are Neuro fuzzy, neural network. Plant is to test the performance in cascade system and it can get a clear procedure to tune the controller. The steady state of output value is one for fuzzy logic controller as well as PID controller. Pilot plant can able to control entire plant in easy manner as compare to other plants. The performance of controller is to tune and optimize according to pilot plant to get back desired output. It is expected that the designed controller into other processes (such as temperature and pressure) can able to measure. In advanced controller (like plc, scada, dcs) improves efficiency and productivity of industrial processes through proper handling of any disturbance or noise and increase the robustness of controller actions.

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