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MATLAB Interfacing: Real-time Implementation of a Fuzzy Logic Controller

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Abstract:-

In this work, the design and evaluation of a fuzzy logic control of liquid flow process is analyzed experimentally using MATLAB package. MATLAB is a widely used software environment for research and teaching applications on control and automation. The interface is a collection of hardware and software modules used to flexibly connect a plant, process or instrument (etc.) to a digital computer. The experimental performance of proposed fuzzy logic control is carried out on existing computer control of flow process. The program of Real-time data acquisition and control has been developed using modules called, "To Instrument" and "Query Instrument" of MATLAB for experimental work. Thus, The present implementation of intelligent fuzzy logic control on real-time basis is a pioneering work at laboratory scale. It is considered to be a great contribution in area of advanced process control systems. The simulation and experimental results clearly shows that the Intelligent Fuzzy Logic Controller gives a better control without overshoots of liquid flow rate in comparison with conventional PID controller.

Key Words: MATLAB, Interfacing, FLC.

1. INTRODUCTION

1.1 Computer Process Interfacing:

The interface is a collection of hardware and software modules used to flexibly connect a plant, process or instrument (etc.) to a digital computer.

The world of plant and process is a continuous spectra of analogue signals, described in the main by *differential equations*. In contrast the world of digital computation is a discrete spectra of digital signals, described mainly by *difference equations*. Communication between these two worlds is essential if digital controllers and intelligent instruments are to be produced. Figure. 1. depicts the signal flow from a plant to a digital computer and back to the plant.

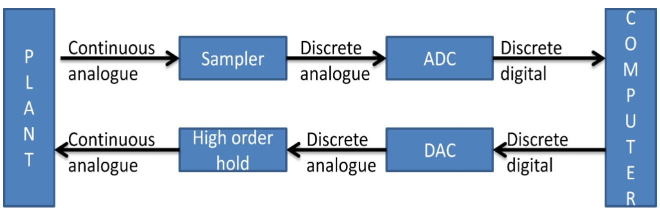

Figure 1: Plant to Computer Signal Flow

The plant (etc.) sensors/transducers generate signals, which become inputs to the digital computer. The plant (etc.) also receives output signals from the digital computer, which operate actuators etc. on the plant. The input-output signals may be analog (both continuous and discrete) or digital (both continuous and pulse). These signals are often processed (transformed or modified). Extensively before they arrive at or leave the digital computers I-O structure.

The Interface is required to control/communicate with a plant or instrument via the interface. The interface must be connected to the digital computer via its I–O Structure.

The Basic I–O Structure Activity: Basic classes of I-O are classified into three types in a digital computer system as follows.

1. Process I – O: Communication to and from the plant or instrument in both analogue and digital formats.
2. Computer I – O: This is connected with managing the digital computer. Deals with machine loading (from disks and magnetic tapes) and machine output (to printers and plotters) in digital format.
3. Operator I – O: Communication with the human user (man/machine interface) mainly in a digital format to visual display units, graphic displays and operators control panels (OCP).

1.2 Real-time Applications using MATLAB:

MATLAB is a renowned and widely used software environment for researching and teaching applications on control and automation, owing to it's vulnerability it has a powerful linear algebra tool, with a very good collection of toolboxes that extend MATLAB basic functionality, with an interactive open environment.

A digital computer is a machine (Hardware) which can manipulate data in digital form according to a predefined set of instructions called a program (Software). parts of a real time system are shown in the below Figure. 2.

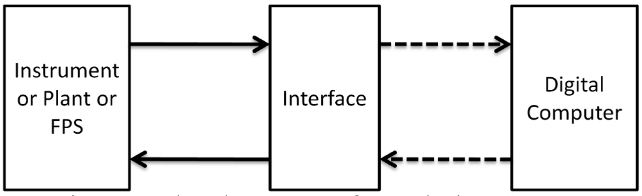

Figure 2: The Three Parts of a Real Time System

2. LITERATURE REVIEW

This section presents a brief report and history of the earlier articles and research papers on PID, FLC.

PID control is one of the earlier control strategies [1] and it's the most popular controller used in process control systems due to its remarkable effectiveness and simplicity of implementation. The technique is sufficient and widely in use for controlling the most of all the industrial processes[2]. It needs very little knowledge about the process for effective controlling[3].

Traditional control methods have poor performances when applied to industrial processes whose models are strongly non-linear and multivariable based. Better results can be obtained by applying modern control techniques [4].

The computational intelligence (CI) techniques, such as Fuzzy Logic(FL) and Artificial Neural Network (ANN), have been successfully applied in many scientific researches and engineering practices [5].

2.1 Fuzzy Logic Control Technique

Fuzzy logic can be easily applied to the most of applications in industry [6]. The great advantage is the possibility to introduce the knowledge of human experts about proper and correct control of a plant in the controller [7].

FL control provides a formal method of translating subjective and imprecise human knowledge into control strategies, thus facilitating better system performance through the exploitation and application of that knowledge [8].

Rahul Malhotra et al [9] studied, the steam flow parameters of a boiler which were controlled by using both conventional PID controller and the optimized using fuzzy logic controller. The comparative results (overshoot, Settling time) show the better results when fuzzy logic controller is used then PID.

Sahil Chandan et al [10] in their study compared the performance of the conventional PID controller and the Fuzzylogic controller. The response of the PID controller was oscillatory which can damage the system. But the response of the fuzzy logic controller was free from these dangerous oscillations in the transient period.

Gaurav et al [11] studied the performance analysis of the conventional PID controller and fuzzy logic controller by MATLAB and in the end comparison of various time domain parameters was done to prove that the fuzzy logic controller had small overshoot and fast response as compared to PID controller.

Jelenka [12] studied and investigated fuzzy logic in process control. The process variables were defined. A multivalued fuzzy system was developed. An intelligent system of the fuzzy logic control was developed for distillate flow rate and quality control by reflux flow rate as manipulated variable. The fuzzy logic control system was developed based on input/output data. This model performed well for the wider operating ranges considered and can be used with confidence for the online control. The obtained results show effective control of state variables in distillation plant. The non stationary characteristics of the process were handled by feeding, information of the state variables, and not only the control error, to the fuzzy logic controller.

3. EXPERIMENTAL WORK

3.1 EXPERIMENTAL SETUP:

The flow measurement technique is to use orifice plate, this comprises orifice plate which is placed in the pipe containing the flowing fluid. Set up as a closed loop control system using an orifice flow meter and controller to process the data.

A schematic diagram of Flow Process is given below in Figure. 3. The flow process station comprises a sump water tank, a pump, a flow transducers (measuring element), a final control element (valve) and an E/P converter is employed.

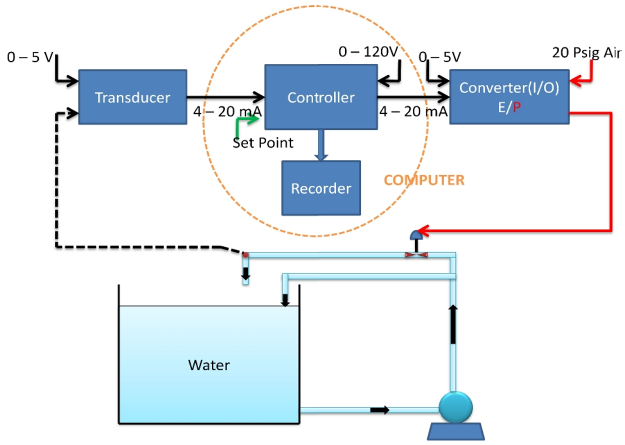

Figure 3.1: Schematic diagram of Flow Process Station

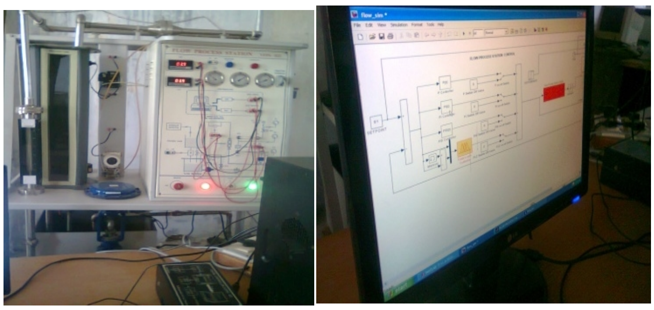

Figure 3.2: FPS experiment setup and Interface.

In this control scheme the main disturbance (volume change in input fluid flow) is measured and controlled using a feedback controller. For this reason an orifice plate along with a Differential Pressure Transmitter (DPT) is used to measure the input fluid flow. The output of the DPT is given to the feedback controller. The control action of feedback controller provided to the valve via the actuator.

The final control element (Valve) is controlled by a programmable power supply providing to 0-5V at 4-20mA. The input of the programmable power supply is 0-5V obtained from a D/A converter connected to the RS-232 output.

3.2 CONTROL OF FLOW PROCESS STATION SYSTEM:

Different assumptions have been considered and derived to develop the control architecture of the Flow process station system. Of them, the first assumption is that the inflow and the outflow rate of fluid are same, so that the fluid level is maintained constant in the pipe. In this feedback process control loop, the controller is reverse acting; the valve used is of air to open type. An orifice plate (transducer) is used as the sensing element, which is implemented in the feedback path of the control architecture. The flow of the outgoing fluid is measured by the orifice plate and the output of the transducer (voltage) is sent to the transmitter unit, which eventually converts the flow output to a standardized signal in the range of 4-20 mA. This output of the transmitter unit is given to the controller unit. In this Flow process station system a Fuzzy Logic Controller has been taken as the controlling unit. The Fuzzy Logic Controller implements the control algorithm, compares the output with the set point and then gives necessary command to the final control element via the actuator unit. The actuator unit is a current to pressure converter and the final control unit is an air to open valve. The actuator unit takes the controller output in the range of 4-20mA and converts it into a standardized pressure unit, i.e. in the range of 3-15 psig. The valve actuates according to the controller decisions. Figure. 4. shows clearly measuring and final control elements.

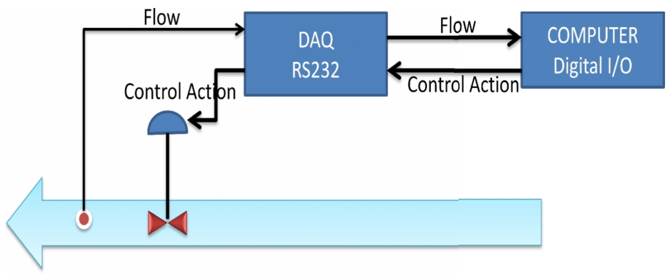

Figure 4: Process-RS232-Computer

3.3 SOFTWARE:

The software is written in MATLAB Script to speed up processing and to communicate with the RS-232. It comprises three sections:

a. Input section: this section receives the pulse train and counts the pulses to provide a frequencies value.

b. Output section: this section outputs a suitable voltage to the final control element (valve) to provide the desired flow.

c. Control section: the control section contains a calibration table between the input frequency from the flow meter and the actual flow obtained from a reference instrument. On receipt of a demanded flow the control routine determines the corresponding pulse frequency and causes the output section to valve.

The performance of Fuzzy and PID is evaluated using the block diagram shown in the Figures. 5. and Figure. 6. for simulation.

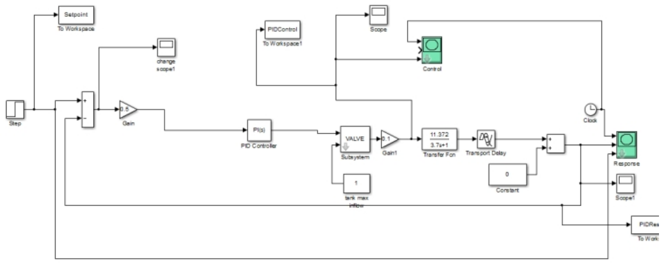

Figure 5: Flow process with PID Controller.

The simulation study was carried out as shown in above Figure. 5. MATLAB - Simulink for PID control system.

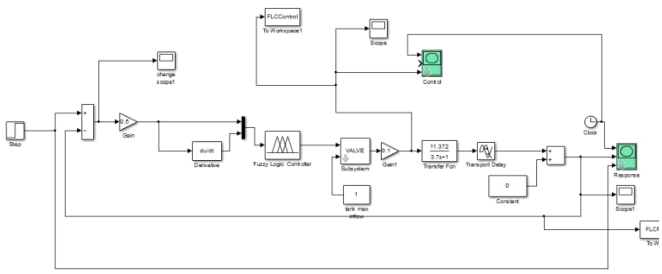

Figure 6: Flow process with FLC Controller.

The simulation study was done as shown in above Figure. 6. MATLAB - Simulink for Fuzzy Logic control system.

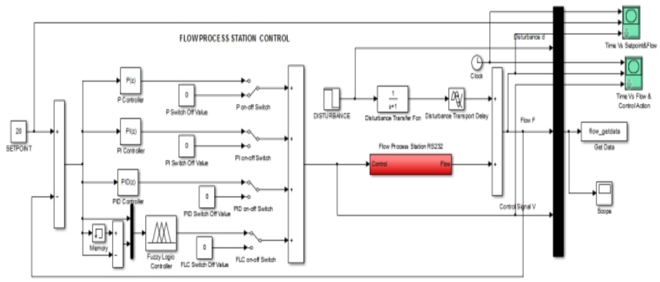

Figure 7: MATLAB Interfacing window.

Figure. 7. shows the MATLAB-Controlling window and Simulink model (With "To Instrument" and "Query Instrument").

3.4 Computer Interfacing Signals Flow:

Table 1: Computer Interfacing I/O Signals Flow

From	To	Signals Units
Orifice Plate	DPT	LPH
DPT	DAQ	mA
DAQ	AD µC 841Controller	V
AD µC 841Controller	Digital Computer	Digital data
Digital Computer	AD µC 841Controller	Digital data
AD µC 841Controller	DAQ	V
DAQ	E/P Converter	mA
E/P	Valve (Open-Close) 3Psig – 0% Open 15Psig – 100% open	Psig (%Valve Open)

4. IDENTIFICATION OF THE PROCESS AND SIMULATION

In this section the identification of flow process is described using Cohn-Cohn method [13]. Later on it shows the use of identified model of the flow process, the PID controller parameters which are obtained by Internal Model Controller (IMC) method. It also deal with the performance of PID controller done through simulation. To determine the transfer function of the flow process experiment by giving step-change in valve opening.

4.1 Flow Process Identification:

By conducting manual experiment, the step response of the flow process is obtained as shown in Figure. 8.

Using the Cohn-Cohn method the flow process is identified as first order with delay. The transfer function with time delay is given by

$$G_p = \frac{K_p}{\tau_P s + 1} e^{-\tau_d s}$$

The process parameters are obtained as $K_p = 11.372, \tau_P = 3.7\, Sec, \tau_d = 1$, substuting the K_p, τ_p, τ_d values in above equation, will give transfer function of process.

$$G_p = \frac{11.372}{3.7s + 1} e^{-1s}$$

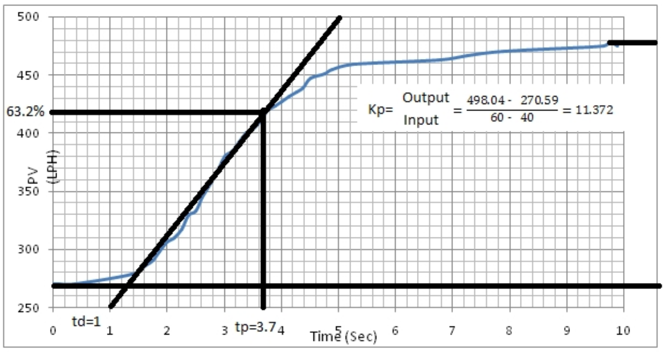

Figure 8: Step response in flow rate for input step change from 40 - 60%.

4.2 Internal Model Control(IMC)-Based PID Design for a First-Order + Dead Time Process[13]:

$$K_c = \frac{\tau_p + 0.5\theta}{K_p(\lambda + 0.5\theta)};\ \tau_I = \tau_p + 0.5\theta;\ \tau_D = \frac{\tau_p \theta}{2\tau_p + \theta}$$

When the process is first-order + dead time. The IMC-based PID controller design parameters are calculated

$K_c = 0.246, \tau_I = 4.2, \tau_D = 0.44.$

5. DESIGN OF A FLC FOR FLOW PROCESS

Design of a fuzzy logic controller requires a sufficient knowledge about the response of the controlled process. The data from the process study constitute the knowledge base for the fuzzy logic controller.

5.1. Steps involved in designing fuzzy control:

The steps involved in designing a simple fuzzy logic controller are as follows:

- Identify the variables (input states and outputs) of the plant.
- Partition the universe of discourse or the interval spanned by each variable into a number of fuzzy subsets, assigning each a linguistic label (subsets include all the elements in the universe).
- Assign or determine a membership function for each fuzzy subset.
- Assign the fuzzy relationships between the inputs or states fuzzy subsets in one hand and the outputs fuzzy subsets on the other hand, thus forming the rule base.
- Choose appropriate scaling factors for the input and the output variables in order to normalize the variables to the [0, 1] or the [-1, +1] interval.
- Fuzzify the inputs to the controller
- Use fuzzy approximate reasoning to infer the output contributed from each rule.
- Aggregate the fuzzy outputs recommended by each rule.
- Apply defuzzification to form a crisp output.

In the fuzzification step, the Flow and flow rate selected as input variables. Universes of discourse of these input variables are divided into three fuzzy sets and they are linguistically named as HIGH, LOW and OK as shown in the Figure. 9. and Figure.10. The Gaussian membership functions with the appropriate ranges have been used for these fuzzy sets. The values of the valve have been selected as Fuzzy output variables.

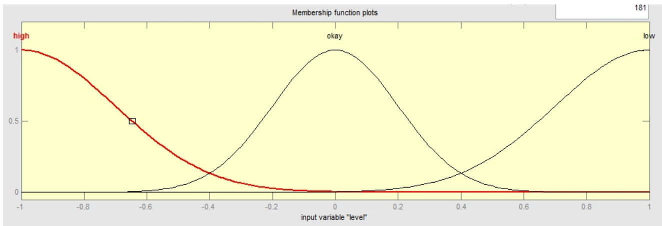

Figure 9: Input membership function of error

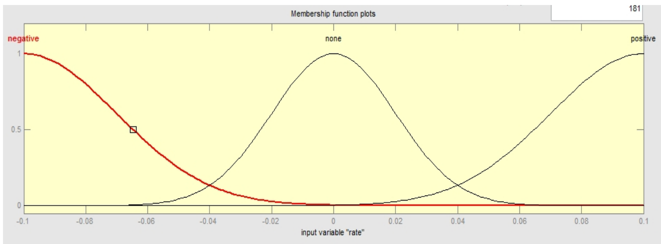

Figure 10: Input membership function of change in error

Like input variables of the universe of discourse the output variables are divided into five fuzzy sets with linguistic names OPENFAST, OPENSLOW, NOCHANGE, CLOSESLOW and CLOSEFAST as shown in the Figure. 11.

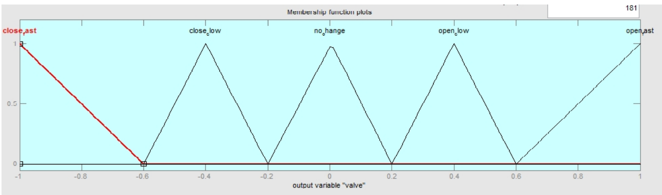

Figure 11: output membership function of valve

The six rules are:

1. *If(Flow HIGH) then (Valve is CLOSEFAST)*
2. *If (Flow is OK) then (Valve is NOCHANGE)*
3. *If (Flow is LOW) then (Valve is OPENFAST)*
4. *If (Flow is OK) and (Flow rate is POSITIVE) then (Valve is CLOSESLOW)*
5. *If (Flow is OK) and (Flow rate is OK) then (Valve is NOCHANGE)*
6. *If (Flow is OK) and (Flow rate is NEGATIVE) then (Valve is OPENSLOW)*

The centroid method has been used to obtain the crisp value.

6. RESULTS AND DISCUSSION

6.1 Simulation Results:

In the simulation we choose set points 300, 500, and 1000 randomly. Initially flow is 0 LPH. The below results are shown comparative studies on PID and Fuzzy Logic Control Systems.

The below comparative simulation results at different set points shows that the fuzzy logic controller have good performance and minimum oscillations than PID Controller and results are Shown in Figures 12-17.

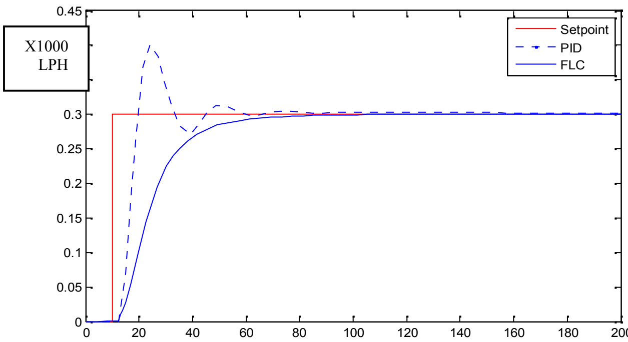

Figure 12: Response of PID & FLC; Vs Time (Sec), for SP=0

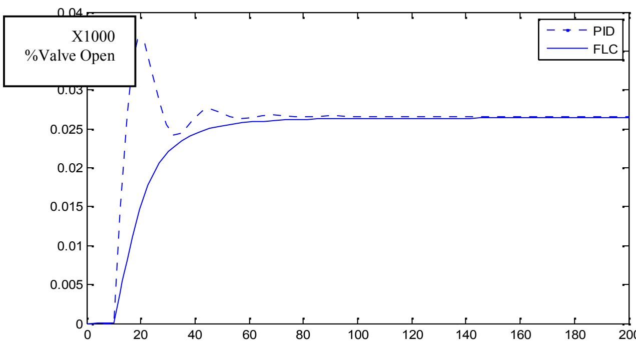

Figure 13: Control Action of PID & FLC; Vs Time (Sec), for SP=0.3.

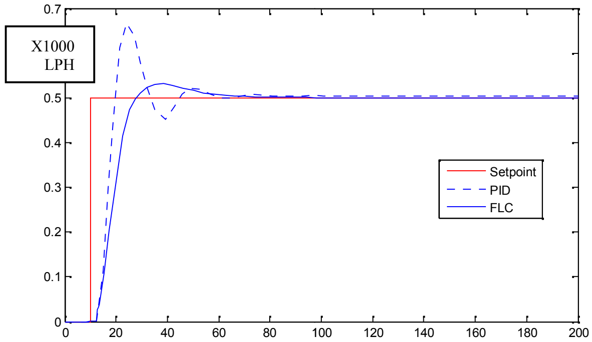

Figure 14: Response of PID & FLC; Vs Time (Sec), for SP=0.5

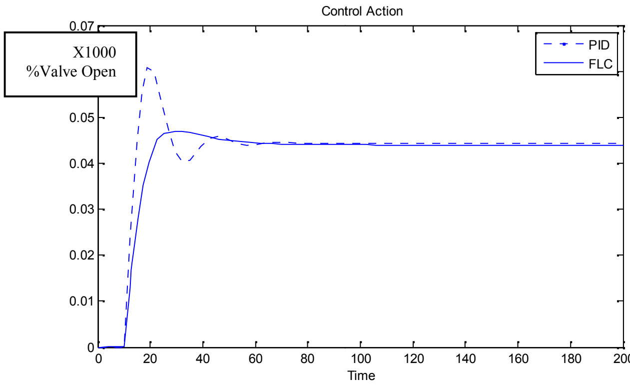

Figure 15: Control Action of PID & FLC; Vs Time (Sec), for SP=0.5.

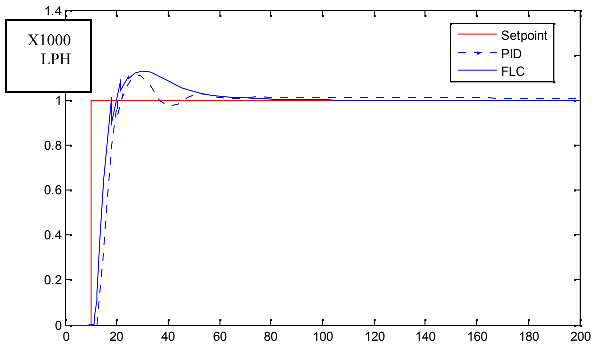

Figure 16: Response of PID & FLC; Vs Time (Sec), for SP=1

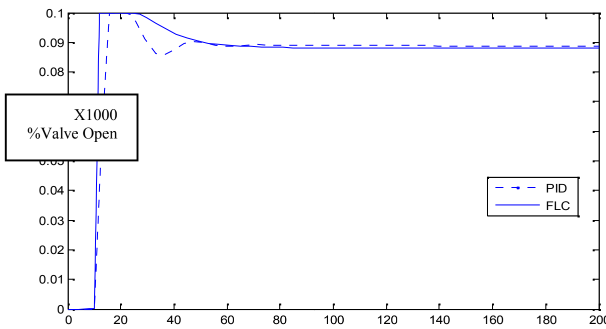

Figure 17: Control Action of PID & FLC; Vs Time (Sec), for SP=1(on Y-axis: 100% valve open is Upper Limit).

6.2 Experimental Results:

In this experiment we choose set points 0, 500, 1000 and 250 LPH randomly. Initially flow is 0 LPH. The below results show comparative studies on PID and Fuzzy Logic Control Systems.
For **PID Control System** to reach the desired set points it will take 30 sec with overshoot and undershoot.
For **Fuzzy Logic Control System** to reach the desired set point it will take 20 sec without overshoot and undershoot.

6.2.1. Comparison of PID and FLC Controllers output response:

The below results clearly show that Fuzzy Logic Control System doesn't have any oscillations (overshoot and undershoot), and gives better Performance as shown in the below Figure. 18. and Figure. 19. both PID and FLC responses.

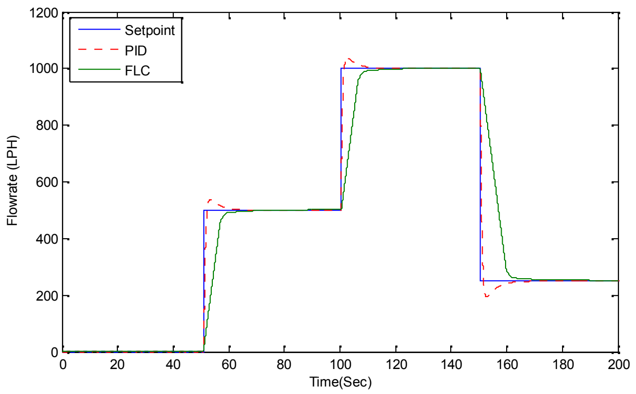

Figure 18: Response of FLC&PID; Flow Rate (LPH) Vs Time (sec), SP1=0, SP2=500, SP3=1000, SP4=250.

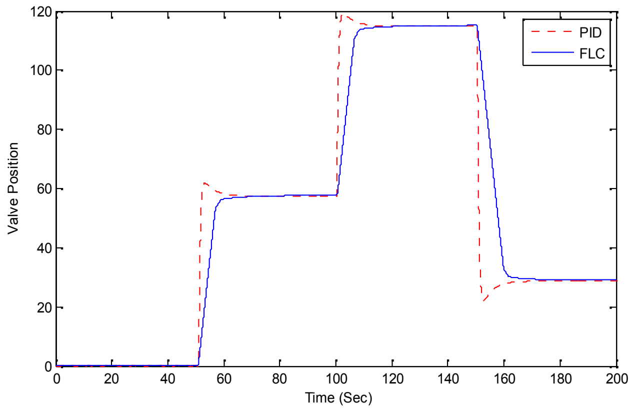

Figure 19: Control action of FLC&PID; Vs Time (sec), SP1=0, SP2=500, SP3=1000, SP4=250.

7. CONCLUSIONS

A unique FLC using a small number of rules and straightforward implementation is proposed to solve a class of flow control problem with unknown dynamics commonly found in flow process station experiment in process dynamics and control laboratory.

As expected the performance, Real-time FLC is found to be superior than conventional PID controller with no overshoot and smaller settling time for liquid flow process.

In this study The FLC and PID experimental results are obtained as same as theoretical results with small difference in over shoot and under shoot.

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