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Conventional PID controller and Fuzzy logic controller for Liquid flow control: Performance Analysis Using MATLAB/Simulink.

Gaurav [*], Amrit Kaur [**]

[*]Student, [**]Assistant professor

University College of engineering,

Punjabi university, Patiala, India

Abstract:

Fuzzy control is based on fuzzy logic-a logical system that is much closer in spirit to human thinking and natural language than traditional logical systems. During the past several years, fuzzy control has emerged as one of the most active and fruitful areas for research in the applications of fuzzy set theory, especially in the realm of industrial processes, which do not lend themselves to control by conventional methods because of a lack of quantitative data regarding the input-output relations. The fuzzy logic controller (FLC) based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy. Fuzzy Logic controller has better stability, small overshoot, and fast response.

Key Words: Flow control, Conventional control, Fuzzy logic control.

I. Introduction

Fuzzy control has emerged one of the most active and fruitful areas of research especially in industrial processes which do not rely upon the conventional methods because of lack of quantitative data regarding the input and output relations. Fuzzy control is based on fuzzy logic, a logical system which is much closer to human thinking and natural language than traditional logical systems [1]. Fuzzy logic controller (FLC) based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy. Fuzzification, defuzzification strategies and fuzzy control rules are used in fuzzy reasoning mechanism [2].

Control of liquid flow system is a routine requirement in many industrial processes. The control action of chemical and petroleum industries include maintaining the controlled variables. Fuzzy logic control (FLC) can be applied for control of liquid flow and level in such processes [1]. This technique is particularly attractive when the process is nonlinear. With most liquid flow measurement instruments, the flow rate is determined inferentially by measuring the liquid's velocity or the change in kinetic energy. Velocity depends on the pressure differential that is forcing the liquid through a pipe or conduit. Because the pipe's cross-sectional area is known and remains constant, the average velocity is an indication of the flow rate. The basic relationship for determining the liquid's flow rate in such cases is:

$$Q = V \times A$$

where,

Q = liquid flow through the pipe

V = average velocity of the flow

A = cross-sectional area of the pipe

Other factors that affect liquid flow rate include the liquid's viscosity and density, and the friction of the liquid in contact with the pipe. Direct measurements of liquid flows can be made with positive-displacement flow meters. These units divide the liquid into specific increments and move it on. The total flow is an accumulation of the measured increments, which can be counted by mechanical or electronic techniques. The performance of flow meters is also influenced by a dimensionless unit called the Reynolds Number. It is defined as the ratio of the liquid's inertial forces to its drag forces.

$$R = \frac{3160 \times Q \times Gt}{D \times \eta}$$

Where R = Reynolds number

Q = liquid's flow rate, gpm

Gt = liquid's specific gravity

D = inside pipe diameter

η = liquid's viscosity

Laminar and turbulent flow are two types normally encountered in liquid flow measurement operations. Most applications involve turbulent flow, with R values above 3000. Viscous liquids usually exhibit laminar flow, with R values below 2000. The transition zone between the two levels may be either laminar or turbulent [2].

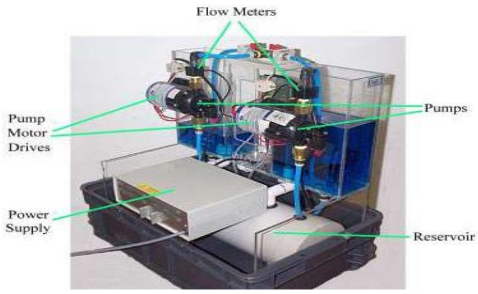

Figure1: Rear View Apparatus of liquid flow control system.

II. FUZZY LOGIC

Fuzzy logic allows defining the control law as a set of simple language inference rules. Fuzzy logic rules are simple and do not require precise control algorithm. Fuzzy logic systems are suitable for approximate reasoning. Fuzzy logic systems have faster and smoother response than conventional systems and control complexity is less [3]. The basic building blocks of a Fuzzy system given below

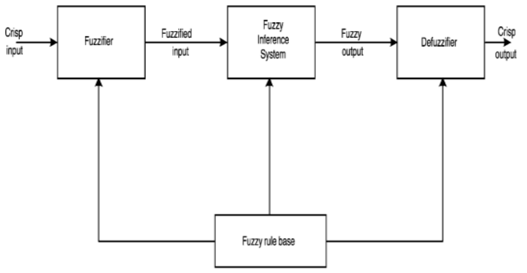

Figure 2: A simple fuzzy system

A simple fuzzy system consists of four blocks: A Fuzzifier, Defuzzifier, inference engine and fuzzy rule knowledge base. The fuzzy set theory describes vague or incomplete concepts that are difficult to formulate mathematically. The centre point of fuzzy system is rule base that contains IF-THENELSE rules. The Fuzzifier maps the crisp input to fuzzy sets defined by their membership functions, whereas the Defuzzifier maps the output fuzzy sets to crisp output values. Fuzzy Logic Controller (FLC) is an attractive choice when precise mathematical formulations are not possible [3]. Other advantages are:

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- It can work with less precise inputs.
- It doesn't need fast processors.
- It is more robust than other non-linear controllers.

III. Why Fuzzy Logic Controller Are Better Than Conventional Controllers?

Fuzzy control has emerged one of the most active and fruitful areas of research especially in industrial processes which do not rely upon the conventional methods because of lack of quantitative data regarding the input and output relations. Fuzzy control is based on fuzzy logic, a logical system which is much closer to human thinking and natural language than traditional logical systems [1]. Fuzzy logic controller (FLC) based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy. Fuzzification, defuzzification strategies and fuzzy control rules are used in fuzzy reasoning mechanism [2]. Kamal et al. concluded the Fuzzy logic control of refrigerant flow. Refrigerant is the medium used to transfer heat from one place to another in refrigeration and air-conditioning systems. Control of refrigerant flow in refrigeration and air-conditioning systems is essential to improve their performance and to prolong their life. The performance of the fuzzy logic controller is compared with a well known existing commercial controller and it shows that the fuzzy logic controller has achieved better performance [3]. Fuzzy logic control is able to handle imprecision and uncertainty.

Fuzzy logic control has been successfully used in various application areas ranging from automatic train operation to flight systems. Fuzzy logic enables control engineers to efficiently develop control strategies in application areas marked by low order dynamics with weak nonlinearities. Fahid et al. [4] concluded that Proportional integrated Derivative (PID) controllers are widely used in process control applications, but they exhibit the poor performance when applied to systems, which are nonlinear, as controller tuning is difficult due to insufficient knowledge of the parameters of the system. Fluid flow system is a typical example.Neuro fuzzy controller gave a better performance compared to the PID controller. It gives better performance with reduced oscillations and faster settling time [5]. The controller performance can still be improved by training the neural network with more number of input and output combinations. Elangeshwaran et al. [6] Overall, fuzzy logic controller is a good alternative to a PID controller, for flow measurement and control applications. From all the above discussions we can conclude that Fuzzy Logic controller has better stability, small overshoot, and fast response.

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IV. Main ideas of FLC

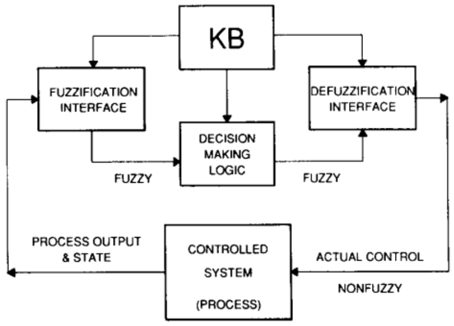

Fig. 2. Basic configuration of fuzzy logic controller (FLC).

Figure 3: Fuzzy logic controller.

Fuzzy logic control is derived from fuzzy set theory. In fuzzy set theory, the transition between membership and non-membership can be graded. Therefore, boundaries of fuzzy sets can be vague and ambiguous, making it useful for approximate systems. Fuzzy Logic Controller (FLC) is an attractive choice when precise mathematical formulations are not possible [3]. Other advantages are:

- It can work with less precise inputs.
- It doesn't need fast processors.
- 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).

V. Problem formulation

A.S. Kamal et al. [3] (1996) set out to apply the fuzzy logic to control the refrigerant flow of a refrigeration system. Fuzzy logic is relatively easy to design and implement. Its performance has been compared with that of a well-known commercial controller. Fuzzy logic achieves better control and improves the performance of the system. The surprising poor performance of the commercial controller could be due to inappropriate setting of the controller gains which cannot be adjusted by users. Fuzzy logic is a viable alternative to conventional forms Fuzzy logic control is able to handle imprecision and uncertainty [3].

Elangeshwaran et al. [9] (2006) illustrates the advantages of a fuzzy based controller over a PID controller are derived from the experiment results. Better control performance, robustness and overall stability can be expected from the fuzzy controller. Fundamentally, the Fuzzy concept is merely a representation of the human cognitive and decision making process hence developing and tuning of the FIS is more intuitive than the PID controller [9].

M.M et al. [12] (2011) concluded that Fuzzy control combined with conventional PID controller constitutes an intelligent control, which adjusts the control parameters depending upon the error. A two input and three output fuzzy adaptive PID control was presented by them. The controller was simulated in MATLAB environment. The simulation results show that the fuzzy adaptive PID controller have better stability, small overshoot, fast response [12].

Fahid et al. [6](2002) concluded that Proportional integrated Derivative (PID) controllers are widely used in process control applications, but they exhibit the poor performance when applied to systems, which are nonlinear, as controller tuning is difficult due to insufficient knowledge of the parameters of the system. Fluid flow system is a typical example.Neuro fuzzy controller gave a better performance compared to the PID controller. It gives better performance with reduced oscillations and faster settling time. The controller performance can still be improved by training the neural network with more number of input and output combinations [6].

Depending on all the above findings and research going on in this field it has been found that flow control has become a highly multi-disciplinary research activity encompassing theoretical, computational and experimental fluid dynamics. It is an emerging field having potential benefits in aerodynamics and bio-medical engineering. So it is proposed that Fuzzy logic flow controller can be implemented.

A) Objectives:

1. To study flow measurement Techniques.

2. To study flow control system using conventional controllers.

3. To study the fuzzy logic system.

4. Design and development for flow control. Proper Fuzzy logic can be implemented for the flow control of fluids.

5. To analyze the controller performance of conventional PID controller and Fuzzy logic controller.

VI. System Design with Fuzzy logic controller:

Fuzzy Logic Control (FLC) has excelled in dealing with systems that are complex, ill-defined, non-linear or time-varying. FLC is relatively easy to implement, as it usually needs no mathematical model of the control system. Fuzzy logic has rapidly become one of the most successful of today's technologies for developing sophisticated control systems. The reason for which is very simple. Fuzzy logic addresses such applications perfectly as it resembles human decision making with an ability to generate precise solutions from certain or approximate information. It fills an important gap in engineering design methods left vacant by purely mathematical approaches (e.g. linear control design), and purely logic-based approaches (e.g. expert systems) in system design. Figure.5 shows the system architecture with Fuzzy logic controller.

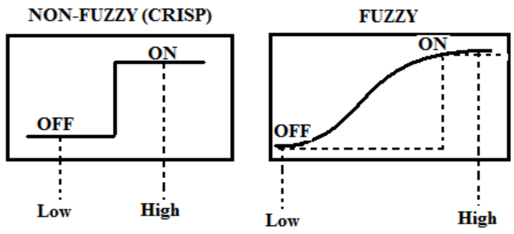

Figure 4: Difference between Crisp and Fuzzy values

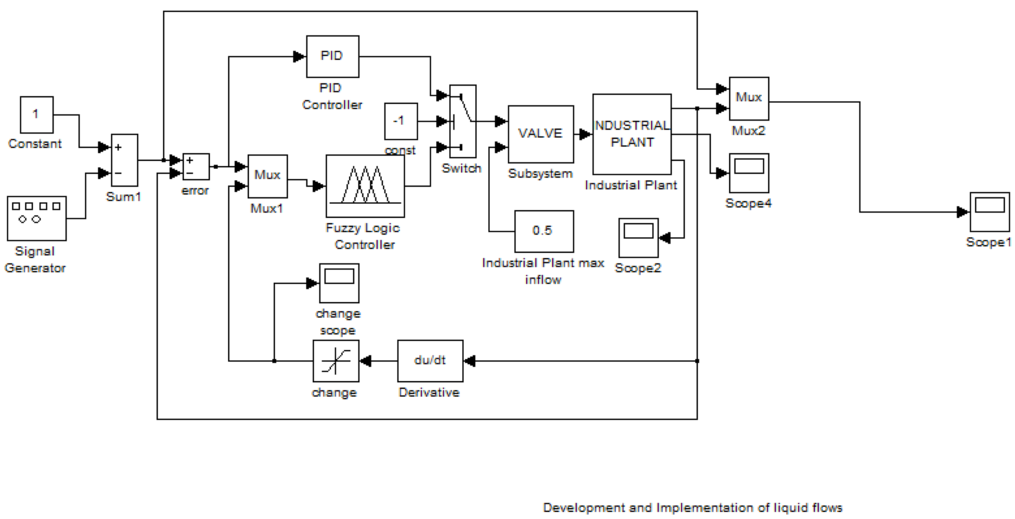

Figure 5: Development and implementation of liquid flows in MATLAB/Simulink Environment.

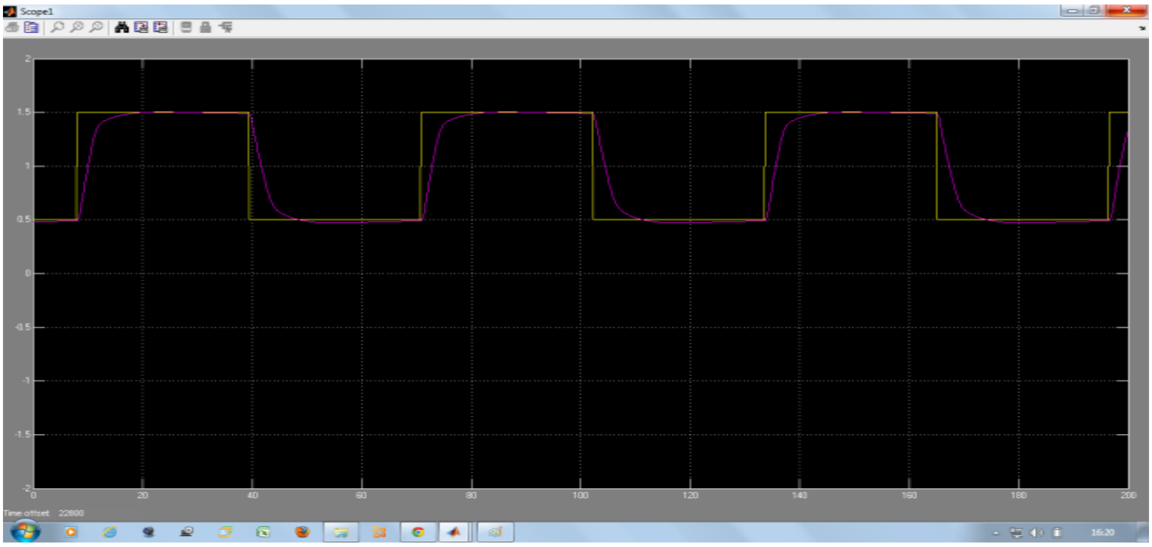

Figure 6: This scope shows the comparative analysis of PID and Fuzzy logic controller.

A. Fuzzy Membership Functions

The fuzzy set is defined by a function that maps objects in a domain of concern to their membership value in the set. Such a function is called membership function and is usually denoted by Greek symbol "μ". Figure 6, shows the selection of number of inputs and outputs in the form of membership functions in order to design FIS. So, it resembles the selection of two inputs – level, rate, and one output –liquid flow. Figure 7, shows the Fuzzy Membership function editor, where the number of membership functions, and type of membership function is chose, such as trapezoidal, triangular, and Gaussian according to the process parameter. The fuzzy logical operation is Fuzzification. For the computation to be relatively simple, the research use triangular shape.

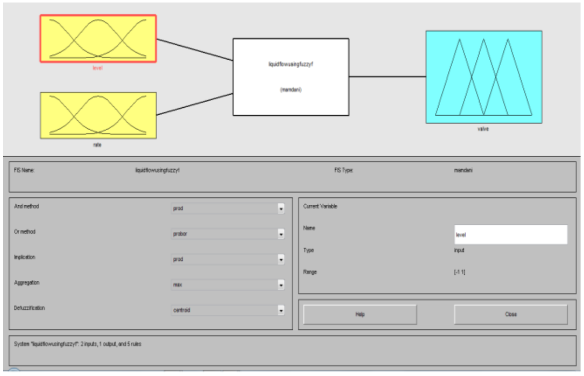

Figure 7: Selection of number of inputs/outputs for designing Fuzzy Inference Structure (FIS) for Fuzzy Logic controller

There are basically two Fuzzification methods namely, Mamdani and Sugeno, and generally used Defuzzification methods are Adaptive integration, Center of area, Center of gravity, Fuzzy clustering Defuzzification, First of maximum, Last of maximum, Mean of maxima, Semi-linear Defuzzification, Quality method, Middle of maximum and centroid method.

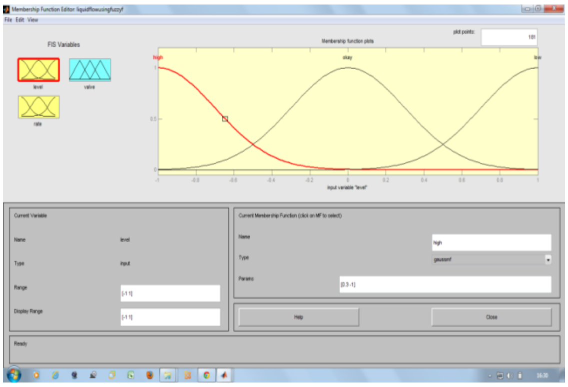

Figure 8: Membership function editor for Fuzzy controller.

B. Fuzzy Inference Structure (FIS) Working

The algorithm of fuzzy rule-based inference consists of four basic steps given as follows.

Fuzzy Matching: - Calculate the degree to which the input data match the condition of the fuzzy rules.

Inference: - Calculate the rule's conclusion based on its matching degree.

Combination: - Combine the conclusion inferred by all fuzzy rules into a final conclusion.
Defuzzification: - For applications that need a crisp output (e.g., in control systems), this step is used to convert a fuzzy conclusion into a crisp one.

C. Fuzzy Rules for Developing FIS

Human beings make decisions based on rules. Although, we may not be aware of it, all the decisions we make are all based on computer like if-then statements (e.g., Table III). If the weather is fine, then we may decide to go out. If the forecast says the weather will be bad today, but fine tomorrow, then we make a decision not to go today, and postpone it till tomorrow. Rules associate ideas and relate one event to another.
IF – THEN FUZZY STATEMENTS FOR FUZZY INFERENCE STRUCTURE (FIS)

Fuzzy machines, which always tend to mimic the behaviour of man, work the same way. However, the decision and the means of choosing that decision are replaced by fuzzy sets and the rules are replaced by fuzzy rules. Fuzzy rules also operate using a series of if-then statements. The fuzzy control rule is based on fuzzy decision-making, which satisfies some input conditions and has an output result.

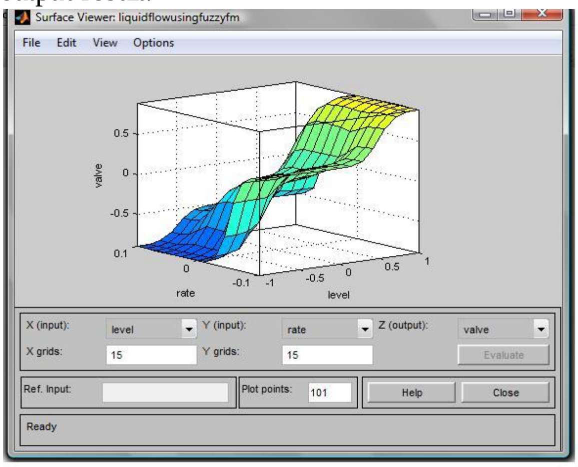

Figure 9: shows the corresponding surface viewer.

VII *Simulation Results*

The Figure 10 11 shows the formation of response of the system when using PID & Fuzzy Logic controllers respectively. Fuzzy logic controller is used in this process because of following reasons:

- It can work with less precise inputs.
- It doesn't need fast processors.
- It is more robust than other non-linear controllers.
- Fuzzy controllers have better stability, small overshoot, and fast response.

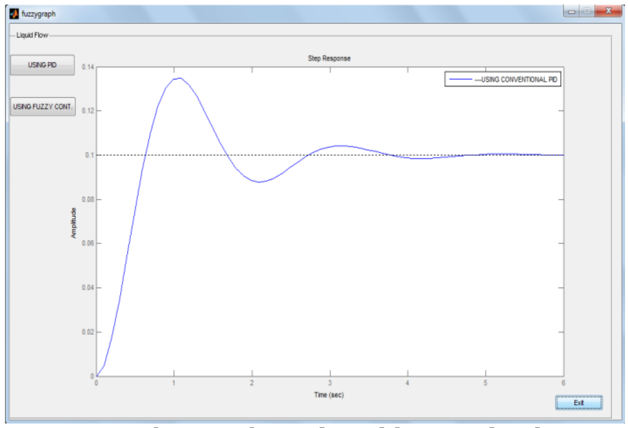

Figure 10: This graph is plotted b/t amplitude and time using Conventional PID shows step response.

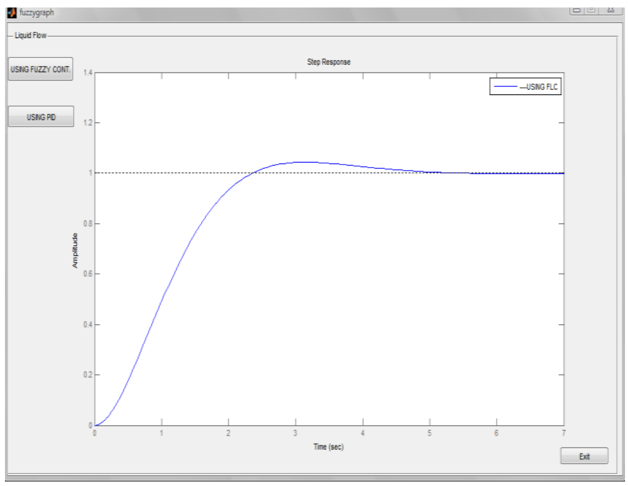

Figure 11: This graph is plotted b/t amplitude and time using Fuzzy shows step response

VIII Conclusion:

Overall the project's feasibility lies in the simplicity of its implementation. The advantages of a fuzzy based controller over a PID controller are derived from results. Better control performance, robustness and overall stability can be expected from the fuzzy controller. Fundamentally, the Fuzzy concept is merely a representation of the human cognitive and decision making process hence developing and tuning of the FIS is more intuitive than the PID controller. Fuzzy control combined with conventional PID controller constitutes an intelligent control, which adjusts the control parameters depending upon the error. Fuzzy controllers have better stability, small overshoot, and fast response.

COMPARING VARIOUS TIME DOMAIN SPECIFICATION

Time Domain Performance Parameters

S.no	Controller Used	Delay Time(Td)in sec	Rise Time(Tr) in sec	Settling Time(Ts) In sec	Peak Overshoot(Mp) in %	Transient Behavior	%Steady State Error(Ess)
1.	PID CONTROLLER	0.1	0.3	16	13	Oscillatory	0
2.	FUZZY LOGIC CONTROLLER	1	1.03	3.85	2.7	Smooth	-6

IX. References:

[1]. Rem Langari,"Past, present and future of fuzzy control: A case for application of fuzzy logic in hierarchical control,"IEEE, pp.760-765, 1999.

[2].Chuen Chien Lee, "Fuzzy logic in control systems i.e. fuzzy logic controller,"IEEE Transactions on Systems, man and cybernetics, Vol 20, No.2, March/April 1990.

[3]. J.Y.M. Cheung, A.S. Kamal," Fuzzy Logic Control of refrigerant flow", UKACC International Conference on Control '96, Conference Publication No. 427, 2-5 September 1996.

[4].Rajanbabu.N, Sreenadhan.S, Fahid K.A, Mohandas K P,"Design and implementation of a neuro-fuzzy controller for a flow system", presentation at FAE symposium, European university of lefke, Nov 2002.

[5]. A. Abdelgawadt, Adam Lewist, M. Elgamelt, Fadi Issa, N.F. Tzeng , and M. Bayoumit," Remote Measuring of Flow Meters for Petroleum Engineering and Other Industrial Applications" The International Workshop on Computer Architecture for Machine Perception and Sensing, pp.99-103, September 2007.

[6].Elangeshwaran Pathmanathan, Rosdiazli Ibrahim," Development and Implementation of Fuzzy Logic Controller for Flow Control Application," Intelligent and Advanced Systems (ICIAS), International Conference on Digital Object Identifier, pp.1-6, 2010.

[7]. R. Manoj Manjunath,S, S. Janaki Raman ," Fuzzy Adaptive PID for Flow Control System based on OPC," IJCA Special Issue on "Computational Science - New Dimensions & Perspectives NCCSE", 2011.

[8].http://en.wikipedia.org/wiki/Flow_meter.

[9].http://www.virtuallaboratories.com/html/fluid_a.html.