Comparison between Conventional PID and Fuzzy Logic Controller for Liquid Flow Control: Performance Evaluation of Fuzzy Logic and PID Controller by Using MATLAB/Simulink

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Abstract:- Measuring the flow of liquids is a critical need in many industrial plants. In recent years, flow control has become a highly multi-disciplinary research activity encompassing theoretical, computational and experimental fluid dynamics. 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. In this Paper, performance analysis of the conventional PID 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.

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

I. Introduction to Fuzzy Logic

The Fuzzy Logic tool was introduced by Lotfi Zadeh (1965), and is a mathematical tool for dealing with uncertainty. It offers to a soft computing partnership the important concept of computing with words. It provides a technique to deal with imprecision. The fuzzy theory provides a mechanism for representing linguistic constructs such as "many," "low," "medium," "often," "few." In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. 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.

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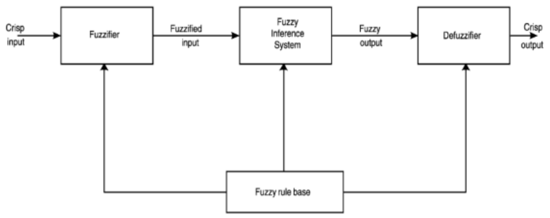

Figure 1: A simple fuzzy system

A simple fuzzy system consists of four blocks: A Fuzzifier, Defuzzifier, inference engine and fuzzy rule knowledge base. 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.

II. Fuzzy Logic Controller Are Better Than Conventional Controllers. WHY?

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].

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 non linearities.

Kamal et al. [4] 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.

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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III 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].

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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 was proposed that Fuzzy logic flow controller can be implemented.

A) Objectives:

- To study flow measurement Techniques.
- To study flow control system using conventional controllers.
- To study the fuzzy logic system.
- Design and development for flow control. Proper Fuzzy logic can be implemented for the flow control of fluids.
- To analyze the controller performance of conventional PID controller and Fuzzy logic controller.

IV Results and Discussions:

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. Fuzzy logic rules are simple and do not require precise control algorithm. Fuzzy logic systems are suitable for approximate reasoning.

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

- It can work with less precise inputs and more robust in nature.
- It doesn’t need fast processors.

A) Liquid Flow Control 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. 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 2 shows the system architecture with Fuzzy logic controller.

B) Simulink Results:

Simulink® is an environment for multi domain simulation and Model-Based Design for dynamic and embedded systems [3].

In this model we can see that Fuzzy logic controller and PID has been used. The difference between them can be seen from change scope.

Figure 2: Development and implementation of liquidflows in MATLAB/Simulink Environme

In scope 1 the yellow line shows input and pink line shows output and it can be seen that output is very close to input.

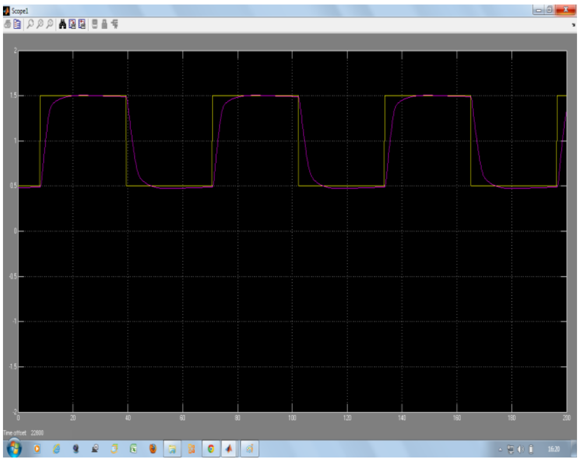

Figure 3: This scope shows the comparative analysis of PID and Fuzzy logic controller.

In change scope we are analyzing the controller performance of conventional PID controller and FUZZY LOGIC CONTROLLER respectively.

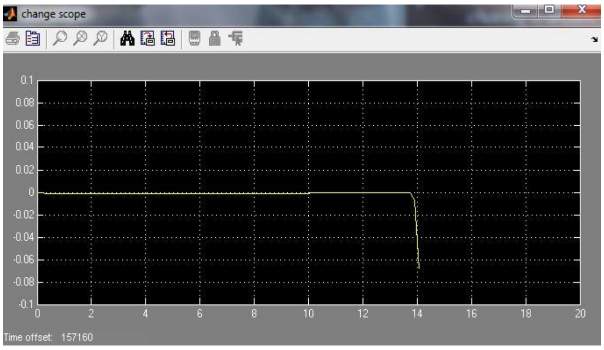

Figure 4: shows the change in scope of conventional controller.

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 valve. 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.

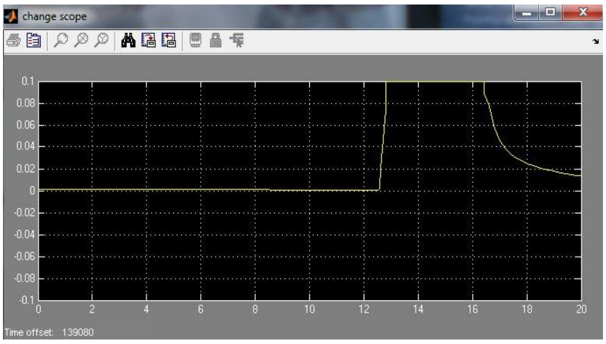

Figure 5: shows the changed scope of controller.

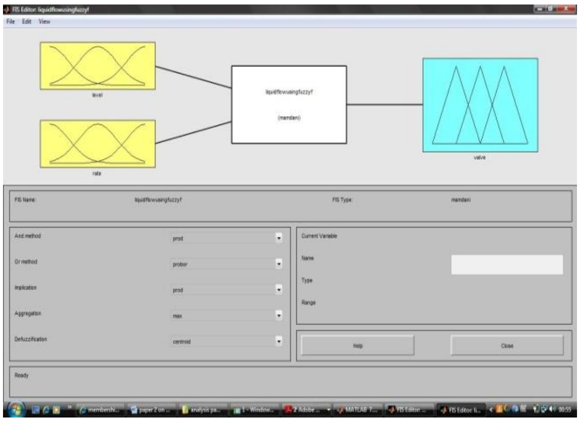

Figure 6: Shows Number of inputs (Level & Rate) and output (Liquid Flow) for designing Fuzzy Inference Structure (FIS) for Fuzzy Logic controller.

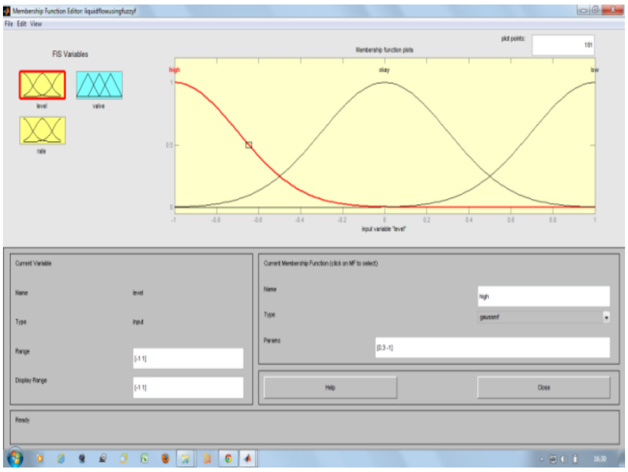

Figure 7: Membership function editor for 2 I/P's (Level & Rate) whose MF is Gaussian and O/P (Valve) whose MF is triangular.

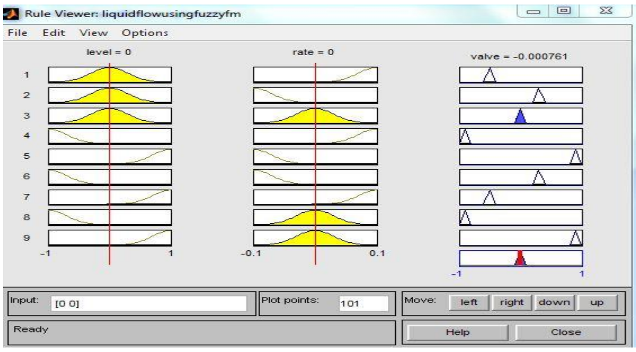

Figure 8: Rule Viewer for Fuzzy controller

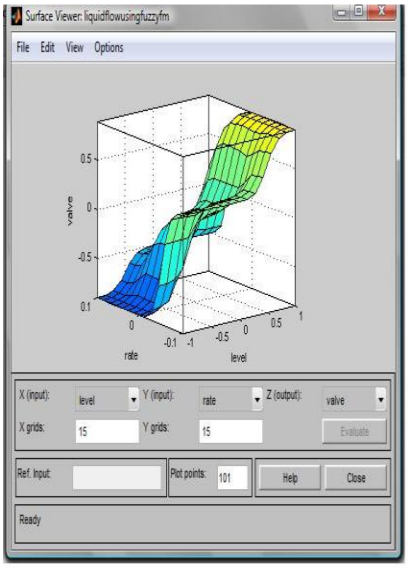

Figure 9: Fig shows the corresponding surface viewer

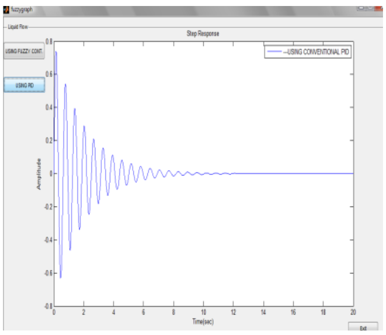

Figure 10: This graph is plotted b/t amplitude and time using Conventional PID shows step response.

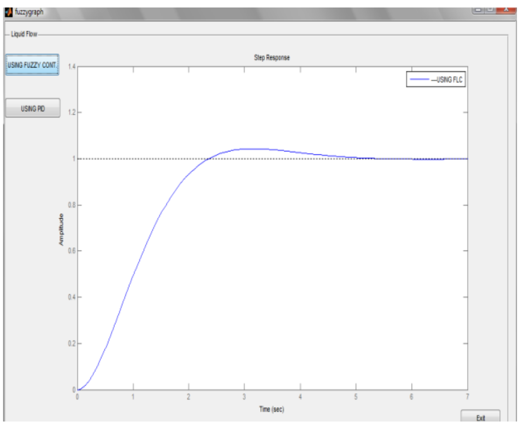

Figure 11: This graph is plotted b/t amplitude and time using Fuzzy shows step response

COMPARING VARIOUS TIME DOMAIN SPECIFICATIONS:

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

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, and
- Centroid method [6].

Basically Defuzzification is the process of converting the fuzzy conclusion into the crisp one and above is the different methods of defuzzification used.

D) Basic Steps of Fuzzy Inference Structure (FIS):

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 [3].

E) 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.

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IF – THEN FUZZY STATEMENTS FOR FUZZY INFERENCE STRUCTURE (FIS)

Fuzzy machines always tend to mimic the behaviour of man .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.

V 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.

After comparing the graphs of conventional PID and fuzzy logic controller as shown in figure10, 11 it is clear that fuzzy logic has small overshoot and is having the fast response as compared to conventional PID Controller. Then, various time domain specifications of both the controllers are compared such as:

- Rise Time(Tr) and Delay Time (Td),
- Settling Time (Ts
- Peak Overshoot (Mp)
- Steady State Error (Ess)
- Transient Behaviour

VI 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. Fuzzy controllers have better stability, small overshoot, and fast response.From the results the following parameters can be observed. Hence, fuzzy logic controller is introduced for controlling fluid flows.

1) Even though, the PID controller produces the response with lower delay time and rise time compared with fuzzy logic controller, but it offers very high settling time due to the oscillatory behaviour in transient period. It has severe oscillations with a very high peak overshoot of 13% which causes the damage in the system performance.
2) The proposed Fuzzy logic controller can effectively eliminate these dangerous oscillations and provides smooth operation in 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 this.

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