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Fuzzy Logic Controller Design for First Order Time Delay Systems

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Abstract: In this paper, a Fuzzy Logic Controller for reducing the time delay (Dead time) is designed. The main purpose of this work is to build a unique FLC which controls the time delay occurring in industries. In most of the industries for controlling time delay PI and PID controllers are used, but when they are compared to FLC the performance parameters such as response time, overshoot is less and accurate in fuzzy. Even it is showed that FLC reduces the Steady state error. Overall, it shows that effect of Fuzziness is more accurate than that of PI and PID controllers.

I. INTRODUCTION

In this paper, a design of fuzzy logic controller for the first-order time delay systems is proposed. Time delay occurs normally in between input and output signals that flows in control system. The time delay systems are frequently occurring in industrial fields such as chemical, biological etc. The fuzzy controllers are used the most in industrial applications and electrical applications, because its design is very simple and its performance is good.

The time delay problem is found in many industrial applications such as, material transport delays in the pipes and rolling mills Dawson, James G., and Zhiqiang Gao. "Fuzzy logic control of variable time delay systems with a stability safe guard." Proceedings of International Conference on Control Applications. IEEE, 1995.. Controlling the system which has time delay is very difficult task. Time delays can be classified into two such as, large delays and small delays. Large delays are the delay that affects the stability of the system very significantly. Many researches are going on to find the controller gains of time delay process. In Dawson, James G., and Zhiqiang Gao. "Fuzzy logic control of variable time delay systems with a stability safe guard." Proceedings of International Conference on Control Applications. IEEE, 1995., authors explain the design of fuzzy controller for time-delay process. Same procedure is used in this paper.

II. LITERATURE SURVEY

In

Cai, Guo-Ping, Jin-Zhi Huang, and Simon X. Yang. "An optimal control method for linear systems with time delay." Computers & structures 81.15 (2003): 1539-1546., they proposed paper on optimal control method, A numerical algorithm for control implementation is presented and time delay is taken at the very beginning of the design. Due to this method, they were able to improve the stability and performance system. This might get Instable in responses if a system with time delay is controlled by the optimal controller that was designed with no consideration of time delay. In

Harshavardhana Reddy, K., et al. "LQR PI Controller Design for First-Order Time-Delay Systems." Advances in Systems, Control and Automation. Springer, Singapore, 2018. 405-413., they used linear quadratic regulator-based PI controller to increase the performance of the system. Using this paper finding the PI gain becomes easier and therefore performance is also enhanced. It is made possible by using Q matrices. In

Chen, Chen, et al. "A time delay compensation method based on area equivalence for active damping of an LCL-type converter." IEEE Transactions on Power Electronics 32.1 (2016): 762-772., they proposed time delay compensation method which is based on area equalization concept. It reduces the negative impact computation delay.

In

Tan, Nusret. "Computation of stabilizing PI and PID controllers for processes with time delay." ISA transactions 44.2 (2005): 213-223., they proposed that it based on the plotting the stability boundary locus and computing it later on to get the stabilize PI values. It does not use linear programming method to solve the solution. Using this method PI controllers gives high phase margins. In

Fridman, Emilia, and Uri Shaked. "An improved stabilization method for linear time-delay systems." IEEE Transactions on Automatic control 47.11 (2002): 1931-1937., they proposed delay-dependent stability and LMI stabilisation using feedback design method, by combining these methods they were able to create a new approach towards time delay method. In

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Quiroga, R. Quian, Thomas Kreuz, and Peter Grassberger. "Event synchronization: a simple and fast method to measure synchronicity and time delay patterns." Physical review E 66.4 (2002): 041904., they developed a method by studying the pattern of time delay and they applied in medical field.
This is method is fast and simple. In

Voss, Henning, and Jürgen Kurths. "Reconstruction of non-linear time delay models from data by the use of optimal transformations." Physics Letters A 234.5 (1997): 336-344., they proposed a method in which by using nonlinear delay differential equation from time series by which they were able to maximum optimisation and numerical accuracy. In

Björklund, Svante, and Lennart Ljung. "An improved phase method for time-delay estimation." Automatica 45.10 (2009): 2467-2470., they proposed a time delay estimation using discrete time model.
The only limitation it has was that it used to fail sometimes. In

Tian, Zhong-Da, et al. "Time-delay compensation method for networked control system based on time-delay prediction and implicit PIGPC." International Journal of Automation and Computing 12.6 (2015): 648-656., they proposed a network time delay compensation method by predict the time delay.it uses LSSVM to predict and through the simulation result they were able to calculate the effectiveness of the design. In

Chai, Qinqin, et al. "A unified parameter identification method for nonlinear time-delay systems." Journal of Industrial and Management Optimization (JIMO) 9.2 (2013): 471-486., they proposed paper they used unified computation to solve the non-linear time delay system. By using this they able to solve dynamic optimization problem.
Above we can see many methods used for reducing time delay, but there are some limitations such as, response time is more, steady state error is more, settling time is high. So, we are designing an AI based controller known as Fuzzy logic controller.

III. FUZZY LOGIC CONTROL

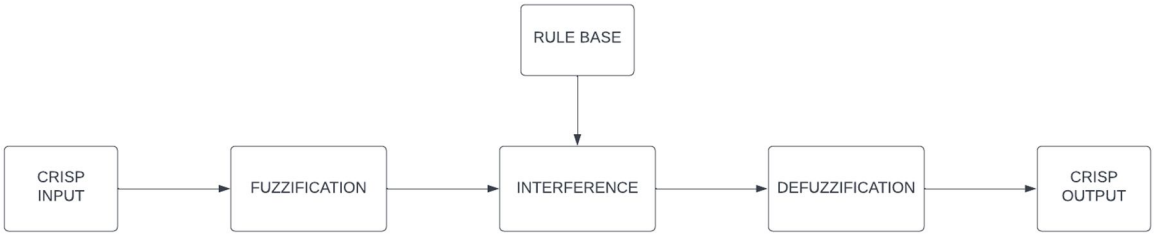


Figure 1 - Block Diagram Of Fuzzy Controller

In Figure 1 - Block Diagram Of Fuzzy ControllerFigure 1 three blocks are present: Fuzzification, interference and defuzzification. First step is fuzzification, and that process involves conversion of crisp input quantity into fuzzy quantity, which will be having full information of the knowledge base. Fuzzification process will use trapezoidal member functions as member functions most of the times. The system will be controlled by rule base which contains set if rules. Those rules will be like “IF X is A then Y is C”

Karthika, S., et al. "Fuzzy Logic Based Maximum Power Point Tracking Designed for 10kW Solar Photovoltaic System with Different Membership Functions." WASET International Journal of Electrical and Computer Engineering 8.6 (2014): 1022-1027.. Based on those set of rules the system will explains the values in input vector and assigns those values to output vector, this process is known as interference, it is the second step. The final block is Defuzzification, it is the process of obtaining single number from the converted fuzzy quantity. Defuzzification can be completed by converting the fuzzy quantity into crisp quantity. In this process we can see the input was crisp quantity and even after undergoing some conversions the output is also crisp quantity. Defuzzification can be completed in various number of ways. The most common method is centroid method.
There are many conventional control methods i.e., when a system follows some characteristics and some detailed information, then it doesn’t understand the information properly and the system models will be complex. But when fuzzy is used it captures the information and attributes of a control system based on observations, Hence the system gets simple. In this paper, a fuzzy logic design method is used to deal with time delay problem for its ability to distinguish the variables, whose values are not known

exactly. The easy structure and less complex shows the proposed fuzzy logic controller are one of the easiest control methods for industrial applications.

IV. DESIGNS OF FLC TIME DELAY PROCESS

$=cs+de-LS$ (1),

$$T(s) = \frac{c}{s+d} e^{-LS} \quad (1)$$

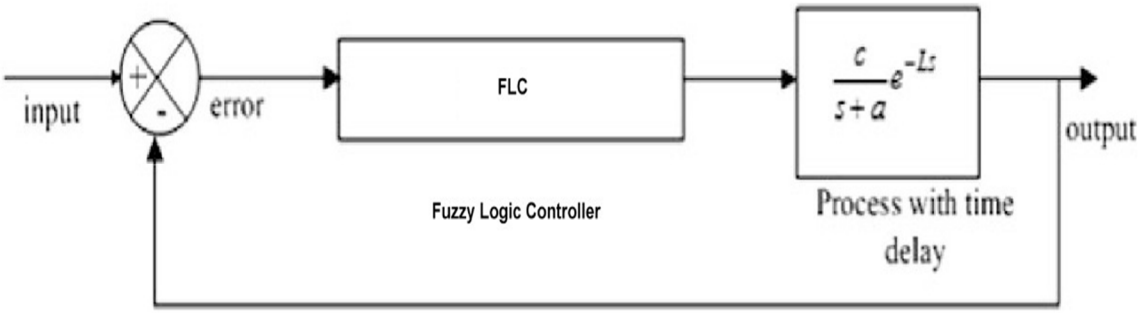


Figure 2 - Block diagram of FLC Time delay system

In Figure 2 - Block diagram of FLC Time delay system we can see that the input provides an error before encountering FLC block [Fuzzy Logic Controller], then comes process with time delay and error is said to be minimised and the same output is given as feedback to the input and process continuous until the error is removed completely.

A. Design of Fuzzy Logic Controller

This is designed in MATLAB SIMULINK. We can give any number of inputs for Fuzzy Logic controller. Those inputs are given to rule editor. According to the rules we given in rule base the controller does the operation and governs the opening of the valve i.e., the output of the FLC and it is denoted by "valve". FIS editor is seen in Figure 3- FIS EDITOR.

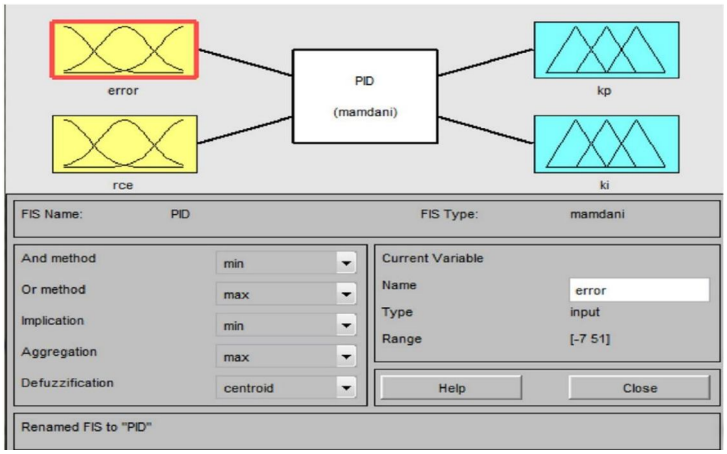


Figure 3- FIS EDITOR

Then membership functions should be given to the inputs and outputs. In Figure 4 (a) Membership editing of the first input variable. (b) Membership editing of the second input variable. (c) Membership editing of the first output variable. (d) Membership editing of the second output variable., the membership function of first input variable can be seen. In Figure 4 (a) Membership editing of the first input variable. (b) Membership editing of the second input variable. (c) Membership editing of the first output variable. (d) Membership editing of the second output variable., we can see the membership function of second input variable. In Figure 4 (a) Membership editing of the first input variable. (b) Membership editing of the second input variable. (c) Membership

editing of the first output variable. (d) Membership editing of the second output variable. , we can see the membership function of first output variable. In Figure 4 (a) Membership editing of the first input variable. (b) Membership editing of the second input variable. (c) Membership editing of the first output variable. (d) Membership editing of the second output variable., we can see the membership function of second output variable. The rules can be given according to the inputs and desired output. The rules of our controller can be seen

Figure 5- Rule Viewer i.e., Rule viewer and in Figure 6 - Surface Viewer, we can see the surface viewer.

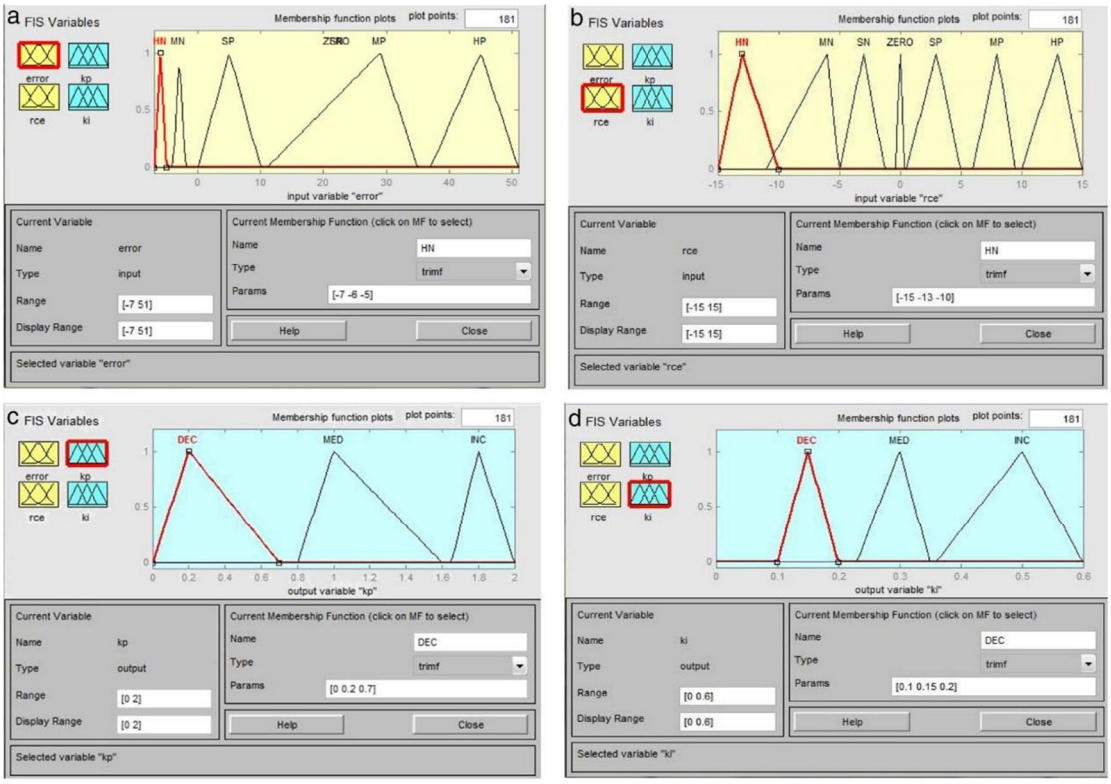


Figure 4 (a) Membership editing of the first input variable. (b) Membership editing of the second input variable. (c) Membership editing of the first output variable. (d) Membership editing of the second output variable.

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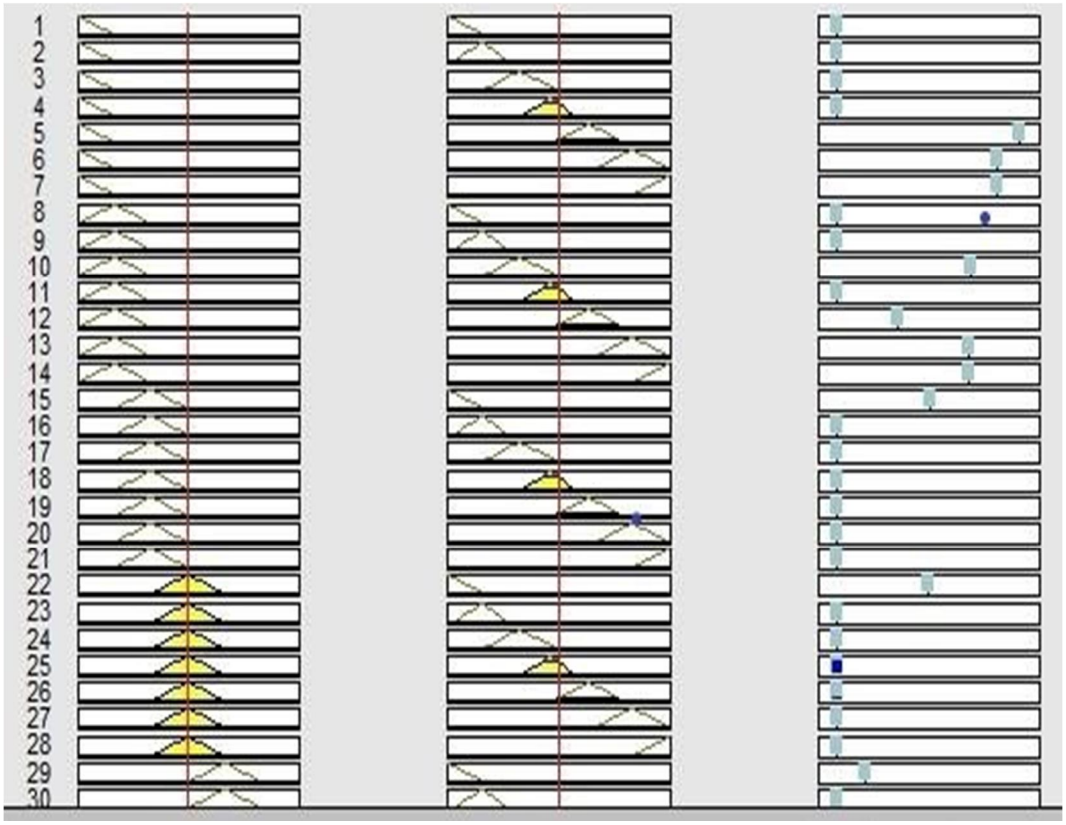


Figure 5- Rule Viewer

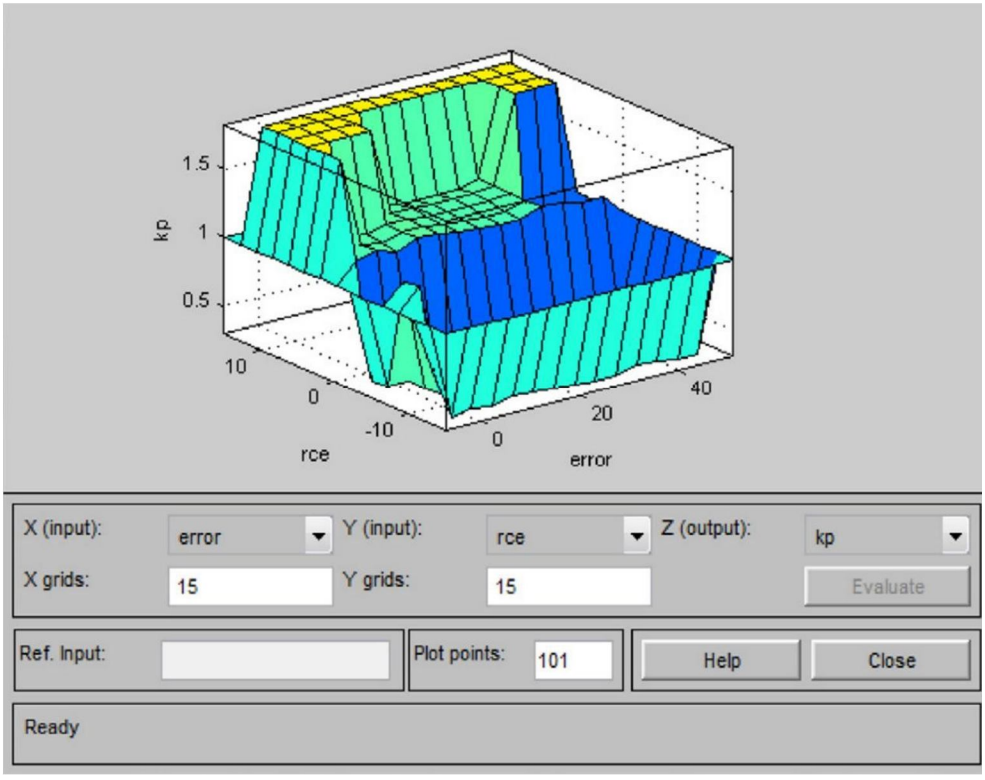


Figure 6 - Surface Viewer

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V. SIMULINK MODEL OF FLC

This is designed in MATLAB SIMULINK. In the Figure 7 - Fuzzy and PID Simulink Model, we can see the Simulink model for fuzzy and PID controller.

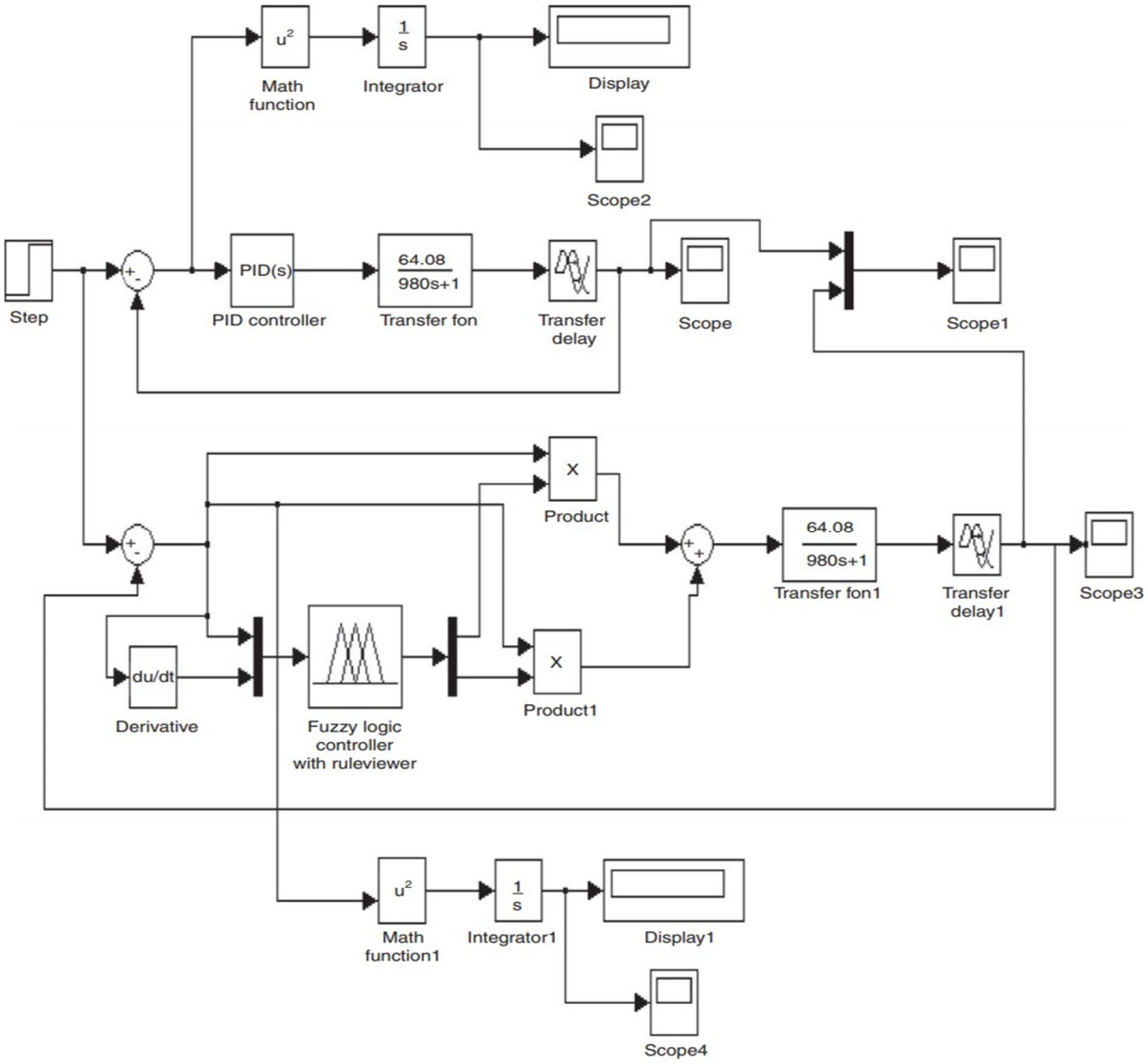


Figure 7 - Fuzzy and PID Simulink Model

VI. SIMULATION RESULTS & DISCUSSION

The results of the Simulink model of FUZZY and PID controller is shown in Figure 8 - OUTPUT RESPONSE FOR TEST CASE 1. Response of Fuzzy and conventional controller are compared, we can see that fuzzy is more accurate and precise than conventional controller. In fuzzy controller, Parameters like peak overshoot, response time, settling time are less and accurate when compared to PID controller.

In test case,

$$G(s) = \frac{1}{s+0.2} e^{-2.5s} \quad (2)$$

Figure 8 - OUTPUT RESPONSE FOR TEST CASE 1shows the output response for equation **Error! Reference source not found.**, it gives two waveforms, black representing FLC and red representing conventional PI controller. The response time is more in PI

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controller compared to that of Fuzzy controller. Table 1 - Comparisons of Performance Indices for Test Case 1, shows the comparisons of performances for test case 1. It tells us the settling time of the PI controller is 24 sec and settling time for proposed Fuzzy Logic controller as 22 sec. The Integral Absolute Error also has come low when compared to PI controller.

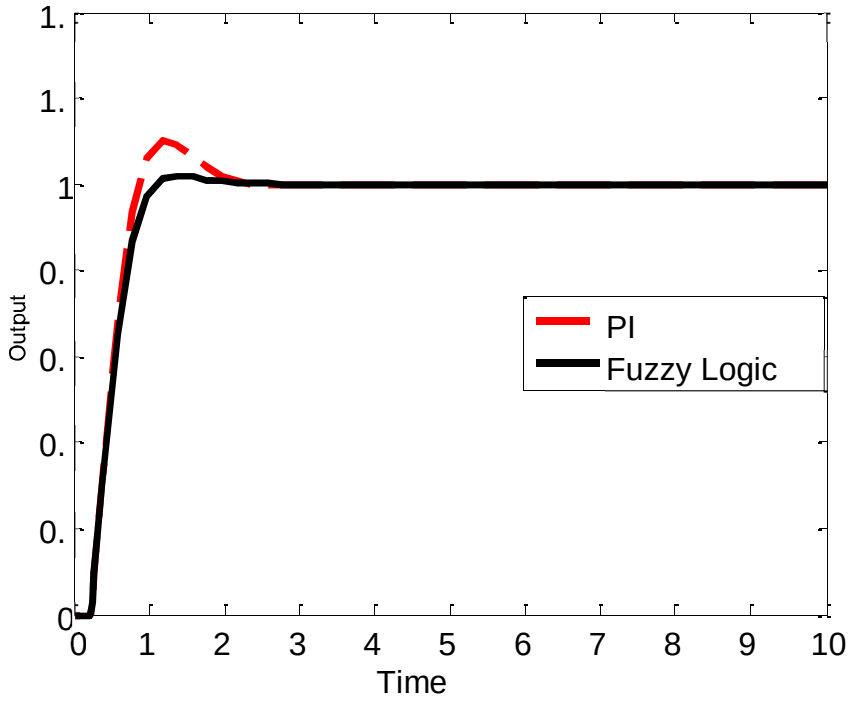


Figure 8 - OUTPUT RESPONSE FOR TEST CASE 1

Test Case 1	Parameters			
	Settling Time	Peak Time	ISE	IAE
PI Controller	24sec	12 sec	95.65	95.83
Fuzzy Logic Controller	22 sec	10sec	93.95	94.96

Table 1 - Comparisons of Performance Indices for Test Case 1

In test case 2, To validate the proposed method let us consider different valur of time delay as shown in equation $\boldsymbol{G(s)} = \frac{\mathbf{1}}{\mathbf{s+0.2}}\boldsymbol{e^{-2s}}$ (3) .

$$G(s) = \frac{1}{s+0.2} e^{-2s} \quad (3)$$

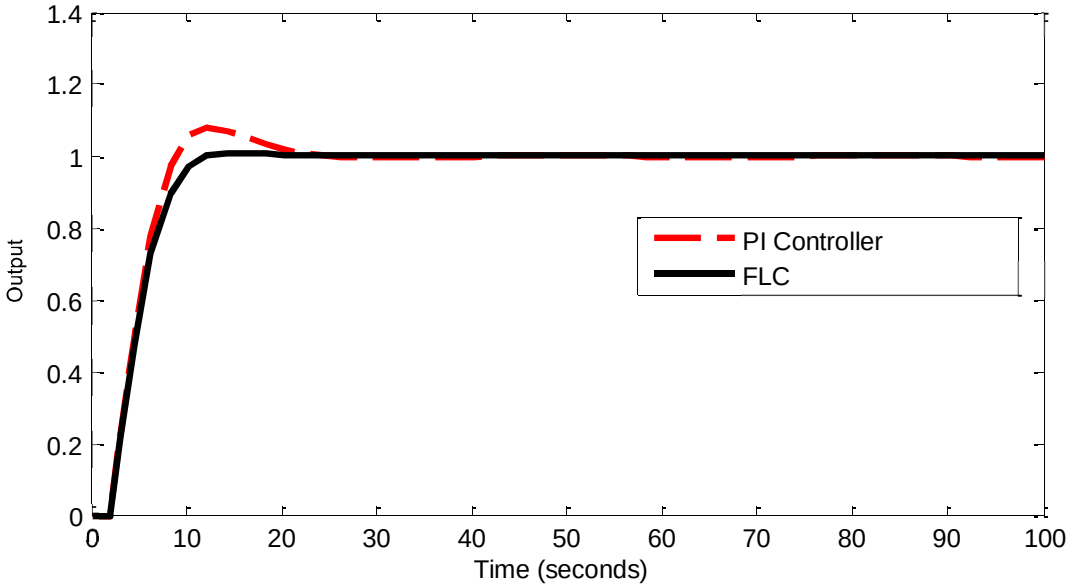


Figure 9 - Output Response for Test Case 2

Test Case 2	Parameters			
	Settling Time	Peak Time	ISE	IAE
PI Controller	22sec	12 sec	90.85	91.77
Fuzzy Logic Controller	18 sec	10sec	87.95	85.51

Table 2 - Comparisons of Performance Indices for Test Case 2

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In Figure 9 - Output Response for Test Case 2 and Table 2 - Comparisons of Performance Indices for Test Case 2, we can see the setting time of the PI controller is 22 sec whereas settling time for proposed Fuzzy Logic Controller as 18 sec. The Integral Absolute Error has also come low when compared to PI controller.

In test case 3, we can see the industrial temperature process, we have developed a Time delay transfer function of Industrial temperature process station. First step collects the input and output data of the process station and with the help of MATLAB LTI tool we have developed the Time delay Transfer Function.

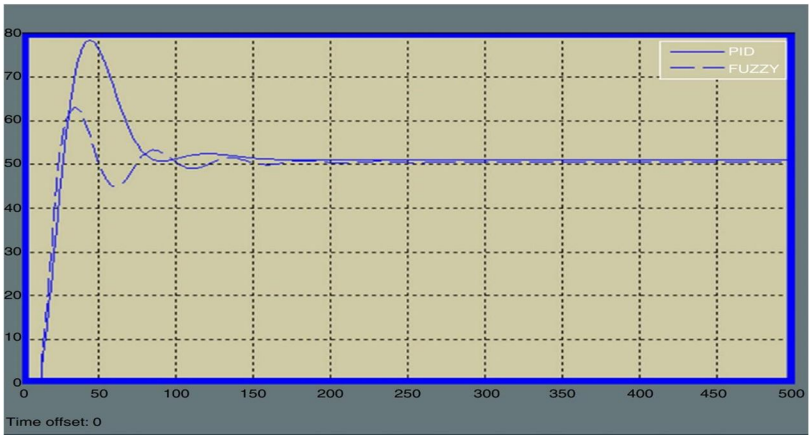


Figure 10- Output Response for Test Case 3.

Controller type	Peak Time	Settling Time	Overshoot
PID Controller	49 sec	170 sec	30
Fuzzy Logic Controller	25 sec	150 sec	12

Table 3 - Comparisons of Performance Indices for Test Case 3.

In Figure 10- Output Response for Test Case 3. and Table 3 - Comparisons of Performance Indices for Test Case 3., we can see the setting time of the PID controller is 170 sec whereas settling time for proposed Fuzzy Logic Controller as 150 sec, and the peak time of the PID controller is 49 sec and Fuzzy Logic Controller is 25 sec. The overshoot has also come low when compared to PID controller.

VII. CONCLUSION

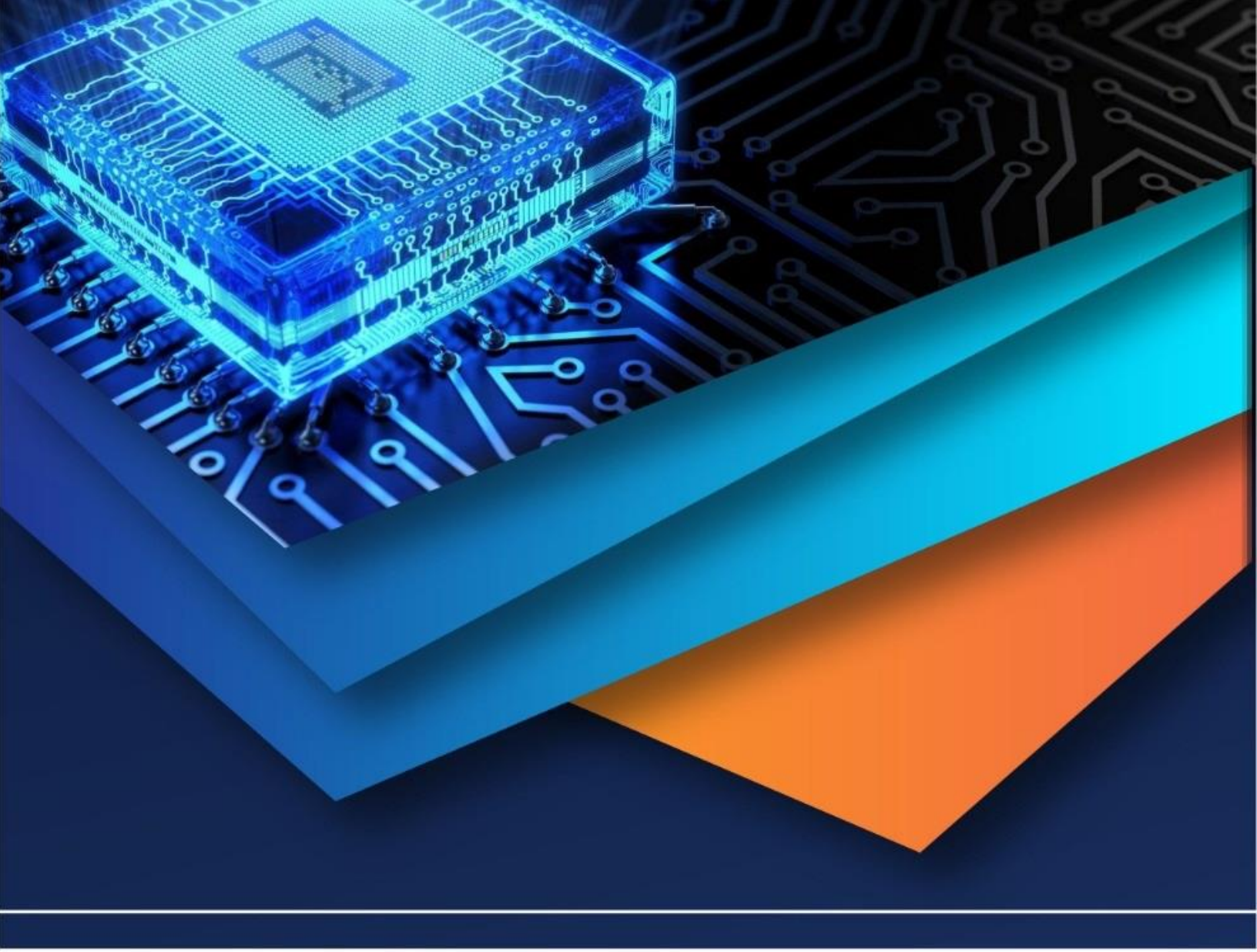
In this paper, the design of Fuzzy Logic Controller is designed for time- delay systems. Here we gave rules to fuzzy to achieve control goals i.e., controlling time delay and getting control gains. Three test cases are considered and simultaneous results are obtained as setction 5. Here the responses and performance parameters of FLC and PID are compared and results shows that FLC is more accurate than PID and efficiency in achieving desired time-domain specifications.

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