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Analysis And Design Of A Fuzzy Controller And Performance Comparison Between The PID Controller And Fuzzy Controller

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Abstract: The paper presents fuzzy control performances by using some different parameters with comparison between fuzzy controller and PID control. Fuzzy control system is a mathematical system which is based on fuzzy logic in contrast to logic. It is broadly used in machine control. For example, the two input variables are "brake temperature" and "speed" that have values defined as fuzzy sets. Based on the simplified model of the system, simulations are carried out for analysis and design this with using some parameters. To study the fuzzy controller system simulations has been carried out in MATLAB 2016 environment. The results confirm improvement of the performance using the developed fuzzy control system.

Keywords: Fuzzy controller, PID controller, Fuzzy sets, Design parameters, Control-system design, Comparison of PID & Fuzzy controller, Tuning.

1. INTRODUCTION

Fuzzy controller has rapidly growing of today's technologies for developing sophisticated control systems since its discovery as actuator privileged in the applications of constant speed, and it has many benefits like good self-starting, less cost and it's simple of design etc. Some fuzzy controllers applications are using in customer products (microwave oven, vacuum cleaner, word translator) in system (train, elevators), in software (medical diagnosis, securities) etc. This logic has some applications which it become like to operate proper answers by approaches of mathematical with logic-based in system design with an ability of human decision making from particular information [1]. It provides an intuitive method for describing systems in the conversion of those system specifications into effective models by using some parameters. The system can be analyzed with classical techniques. It is described by the binary logic of classical sets. The complete paper is demonstrated as in a recent work, analyzed, designed, simulated with MATLAB Simulation and practically implemented. Besides, the performance and effectiveness of some standard and improved fuzzy controller and compared with PID controller.

2. OBJECTIVES

The objectives of this article are:

- To develop the model of Fuzzy control in MATLAB/Simulink.
- To simulate the model and analyze it for various operating conditions with some transfer function.
- To analyze the performance of system by changing the parameters
- To compare between PID controller and Fuzzy controller
- Interpretation of the results obtained through simulation.

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3. MATERIALS AND METHODS

3.1 Fuzzy logic Introduction:

Fuzzy logic is a critical thinking control framework procedure that fits execution in frameworks running from basic, little, inserted microcontrollers to huge, arranged, multi-channel PC or workstation-based information procurement and control frameworks. Fuzzy logic can be executed in equipment, programming, or a mix of both [2] [3].

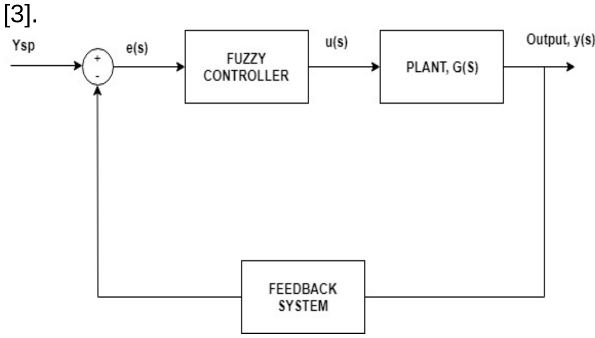

***Fig. 1**- Structure of a Fuzzy Controller System*

3.2 Fuzzy Control System:

A fuzzy control system is based on Fuzzy Logic. The process of designing fuzzy control system can be described using following steps

Step 1: Identify the principal input, output and process tasks
Step 2: Identify linguistic variables used and define fuzzy sets and memberships accordingly
Step 3: Use these fuzzy sets and linguistic variables to form procedural rules
Step 4: Determine the defuzzification method
Step 5: Test the system and modify if necessary

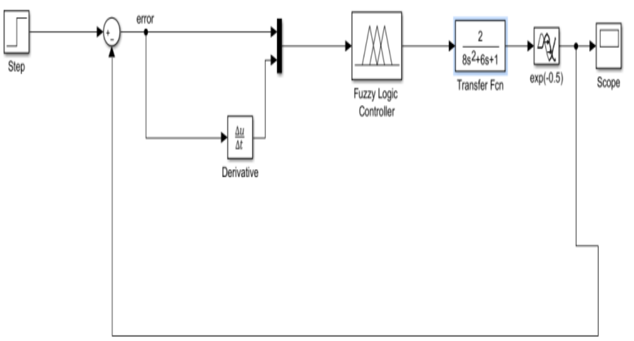

***Fig. 2**- The simulation block diagram of Fuzzy PID control system*

***Table 1-** How to fix a fuzzy controller*

What's wrong	What to do
Fuzzy controller does. not provide stability to the system	1. By changing the structure of the control system. 2. Check the rules table: sometimes one needs to change an incorrect sign in the rules output. 3. Decrease the output scaling factor.
Overshoot (output oscillation magnitude) is too high	1. Decrease the output scaling factor of the fuzzy controller. 2. In a PID-like fuzzy controller, decrease the output scaling factor of the PD-part
Speed of response is too low (rise time is too long)	1. In a PID-like fuzzy controller increase the output scaling factor of the PD-part. 2. Increase the scaling factor for a differential input compared to other inputs.
Poor steady-state accuracy	1. Reduce the width of the membership function for the zero class of the error signal. 2. Redistribute the membership functions, increasing their concentration around the zero point.

3.3 Design Parameters:
The models of known control objects are,

$$G(S) = \frac{Ke^{-\tau s}}{(T_1 s + 1)(T_2 s + 1)}$$

When K = 2, τ = 0.5, T_1 = 2, T_2= 4, designed Fuzzy controller and analysis:

3.4 Fuzzy Controller Design:
Fuzzy logic is really a numerical strategy which permits with various input and output variables. The plan of technique begins with the input [1]. There are three linguistic variables chosen for the design. Positive (P), Negative (N), Zero (Z).The membership function chosen by some different shaped like error is trapezoidal shaped, errorchange is Gaussian shaped and output is the triangular shaped. Here Mamdani type fuzzy is used.

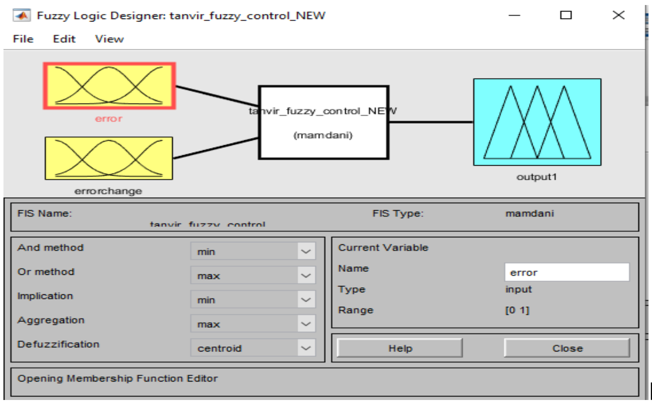

Fig. 3- Fuzzy Logic Editor Interface in MATLAB

3.5 Database of Fuzzy Rules:
For this design two input variables – error (e) and errorchange (ec) and an output variable control (u).We can define these variables in MATLAB using fuzzy logic FIS editor. In this design five membership functions are defined.

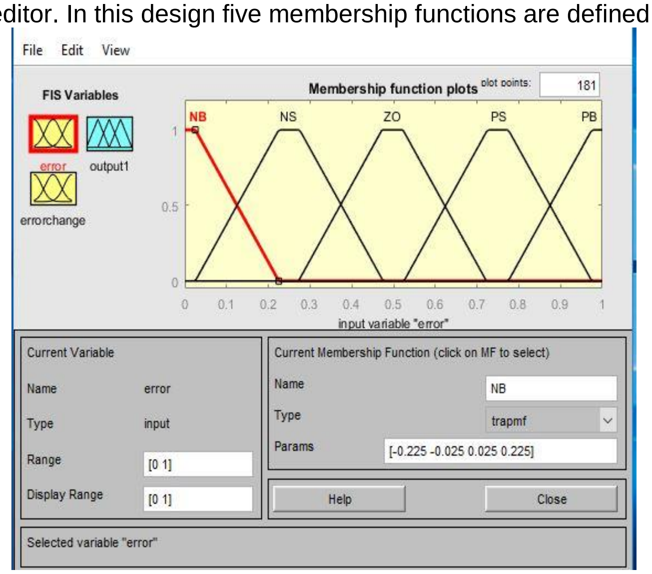

***Fig. 4**-Membership Function of Input*

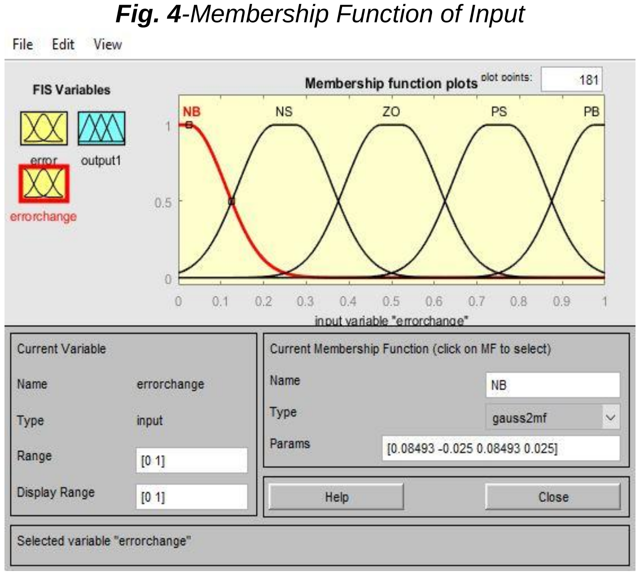

***Fig. 5**- Membership Function of Errorchange*

3.6 Fuzzification:

The process of transforming crisp (bivalued) input values into linguistic values are called fuzzification.
Steps for Fuzzification:
Step 1: Input values are translated into linguistic concepts, which are represented by fuzzy set.
Step 2: Membership functions are applied to the measurements, and the degree of membership is determined.

3.7 **Defuzzification:**

Defuzzification converts the fuzzy values into crisp (bivalued) value. Example methods of defuzzification.
• Max-membership method: This method chooses the elements with maximum value
• Centroid method: This method finds the center point of targeted fuzzy region by calculating the weighted mean of the output fuzzy region
• Weighted average method: Assigns weight to each membership function in the output by its respective maximum membership value

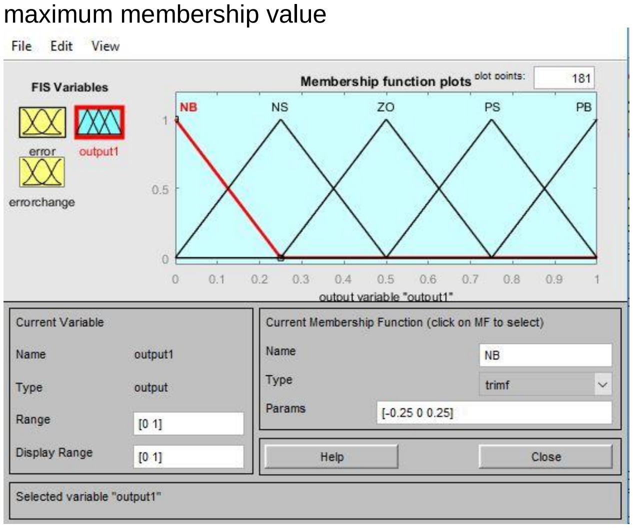

Fig. 6*- Membership Function of Output*

In this simulation, we partitioned a space of input and output variables into 5 fuzzy subsets. They are presented by 5 membership functions as in the Table 1. These functions are:
• Negative Big (NB)
• Negative Small (NS)
• Zero (ZO)
• Positive Small (PS)
• Positive Big (PB)
The different rules used in this design are shown below

Table 2- *Different rule base for fuzzy logic control*

e / ec	NB	NS	ZO	PS	PB
NB	NB	NS	NB	NB	ZE
NS	NS	NS	NB	ZE	PB
ZO	NB	NB	ZE	PB	PB
PS	NB	ZE	PB	PS	PS
PB	ZE	PB	PB	PS	PS

Fuzzy Logic Rules for control:

- If (error is NB) and (errorchange is NB) then (output1 is NS)
- If (error is NB) and (errorchange is NS) then (output1 is NS)
- If (error is NB) and (errorchange is ZO) then (output1 is NB)
- If (error is NB) and (errorchange is PS) then (output1 is ZO)
- If (error is NB) and (errorchange is PB) then (output1 is NB)
- If (error is NS) and (errorchange is NB) then (output1 is NS)
- If (error is NS) and (errorchange is NS) then (output1 is NS)
- If (error is NS) and (errorchange is ZO) then (output1 is NB)
- If (error is NS) and (errorchange is PS) then (output1 is PB)
- If (error is NS) and (errorchange is PB) then (output1 is ZO)
- If (error is ZO) and (errorchange is NB) then (output1 is NB)
- If (error is ZO) and (errorchange is NS) then (output1 is NB)
- If (error is ZO) and (errorchange is ZO) then (output1 is ZO)
- If (error is ZO) and (errorchange is PS) then (output1 is PB)
- If (error is ZO) and (errorchange is PB) then (output1 is PB)
- If (error is PS) and (errorchange is NB) then (output1 is NB)
- If (error is PS) and (errorchange is NS) then (output1 is ZO)
- If (error is PS) and (errorchange is ZO) then (output1 is PB)
- If (error is PS) and (errorchange is PS) then (output1 is PS)
- If (error is PS) and (errorchange is PB) then (output1 is PS)
- If (error is PB) and (errorchange is NB) then (output1 is ZO)
- If (error is PB) and (errorchange is NS) then (output1 is PB)
- If (error is PB) and (errorchange is ZO) then (output1 is PB)
- If (error is PB) and (errorchange is PS) then (output1 is PS)
- If (error is PB) and (errorchange is PB) then (output1 is PS)

3.8 Fuzzy controller design can be summarized as follows:
1) Fuzzy set of fuzzy rules is being determined;
2) With help of membership function, fuzzification of the input is done and fuzzy output is done.

4. THE CONTROL SYSTEM PERFORMANCE

4.1 Performance Parameters of Fuzzy Controller System:

In this design have two input variables – error (e) and errorchange (ec) and an output variable control (u) and The membership function chosen by some different shaped like error is trapezoidal shaped, errorchange is Gaussian shaped and output is the triangular shaped.
From Step response plot (Fig. 7) it shows,

Table 3- *Performance parameter and Output response*

Serial No.	Performance Parameter	Output Response
1	Rise time(sec)	1.944S
2	Overshoot percentage (%)	34.459%
3	Settling time(sec)	Undefined
4	Final steady state value	0.35

From the Fig. 7 the performance of fuzzy controller system not gained good performance for the lack of steady state value. The ideal value of steady state is 1.

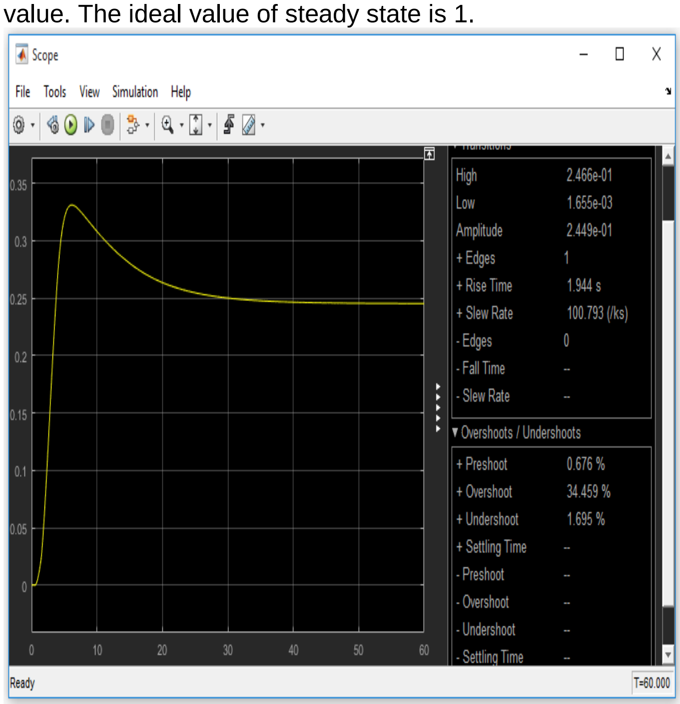

Fig. 7- *Unit Step Response Plot of Fuzzy Controller System*

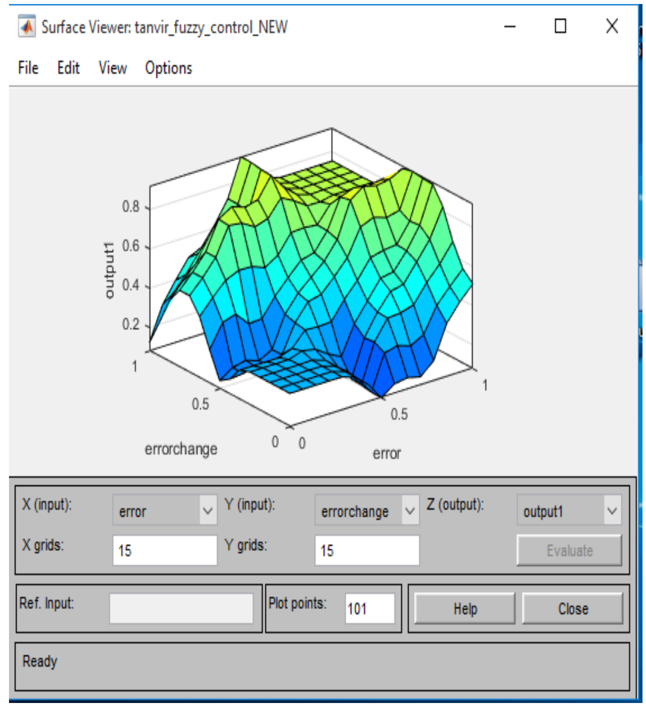

Fig. 8- *Control Surface viewer between inputs and outputs variable of fuzzy control*

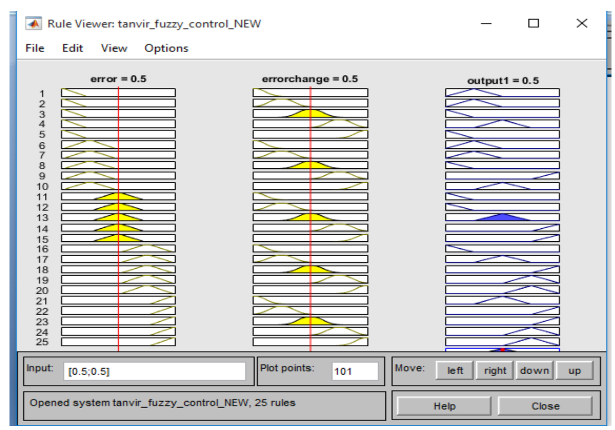

Fig. 9- *Rule viewer of fuzzy control*

4.2 Now the parameters of the controller changes, the influence on the control system performance:

Control system (Fig. 7 or Table 3) need to gain good performance by changing Fuzzy controller structure and parameter choice such as choice of structure, choice of inputs (The same as for a conventional control system The error and change of error signals are often applied as the inputs for a fuzzy controller), Choice of membership function, choice of the rules, decision of the defuzzification technique (Choose Mamdani technique Choose Sugeno) etc. [4]. Every set of fuzzy can be represented by its membership function. If change all parameters (error, errorchange & output) to triangular membership function its shows (in Fig. 10). Recalling previous error was trapezoidal, errorchange was triangular and output variable was Gaussian membership function.

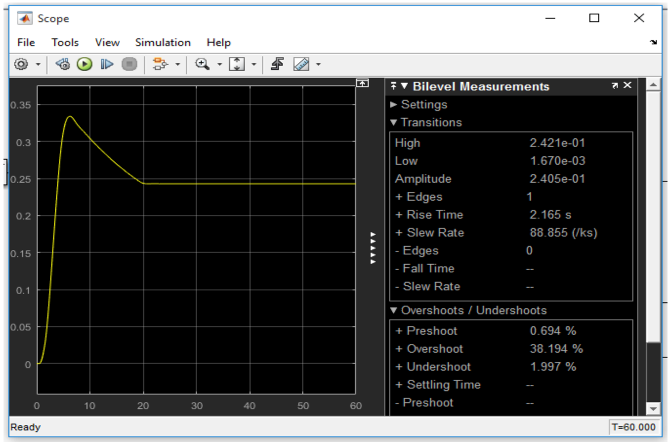

***Fig. 10**- Unit Step Response of Fuzzy Controller System (Modified)*

***Table 4**- Performance parameter and Output response (Modified)*

Serial No.	Performance Parameter	Output Response
1	Rise time(sec)	2.165S
2	Overshoot percentage (%)	38.194%
3	Settling time(sec)	Undefined
4	Final steady state value	0.35

It can be seen from the response that the previous one is little better cause rise time and overshoot is too high here and steady state value is remain same.

4.3 The parameters of the model changes:

When the parameters of the model changes and the controller parameters remain constant, the influence on the performance of the control system

The value of K is changed to 4.5 from 2

$$G(S) = \frac{Ke^{-\tau s}}{(T_1 s + 1)(T_2 s + 1)}$$

When K = 4.5, τ = 0.5, T_1= 2, T_2 = 4

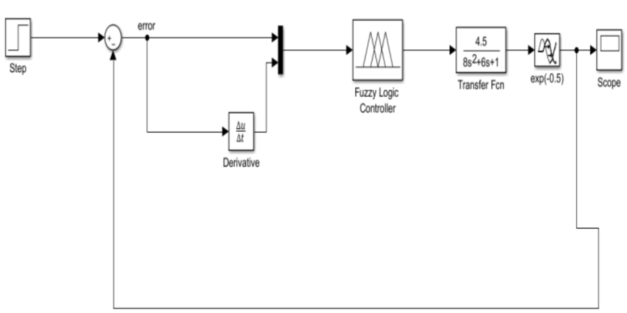

***Fig. 11**- Simulation block diagram of Fuzzy PID control system (Modified)*

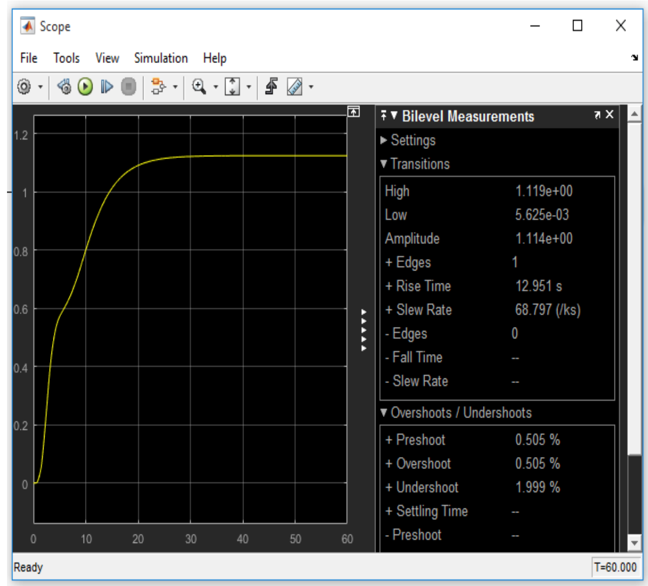

***Fig. 12**- Unit Step Response of Fuzzy Controller System*

***Table 5**- Performance parameter and Output response*

Serial No.	Performance Parameter	Output Response
1	Rise time(sec)	12.951S
2	Overshoot percentage (%)	0.505%
3	Settling time(sec)	Undefined
4	Final steady state value	1.1 (almost)

5. PERFORMANCE BETWEEN THE PID CONTROLLER ANF FUZZY CONTROLLER

P - Depends on present error

I - Depends on accumulation of past errors

D - is a prediction of future errors

A proportional integrating derivative controller is a generic control loop feedback mechanism widely used in industrial control systems. A PID regulator computes a "mistake" esteem as the distinction between a deliberate cycle variable and an ideal set-point. The regulator endeavors to limit the blunder by modifying the cycle control inputs [5].

5.1 Three parameters:

1. Proportional Gain (Kp): Quick response lead to instability and oscillation process instability.
2. Integral Gain (Ki): Larger values imply steady state errors are eliminated
more quickly.
3. Derivative Gain (Kd): Overshoots decrease.

Thus, the design phase of PID controller, there is a crucial and challenging task for setting the system. PID parameter for plant can be evaluated by either Ziegler-Nichols empirical formula or using self-tuning in MATLAB in-built function.

5.2 PID controller design:

***Table 6**- Optimum response list*

Constants	Rise time	Overshoot	Settling time
Kp ↑	Decrease	Increase	Small change
Ki ↑	Decrease	Increase	Increase
Kd ↑	Small change	Decrease	Decrease

The values of Kp, Ki, and Kd are adjusted until we obtain the optimum response.

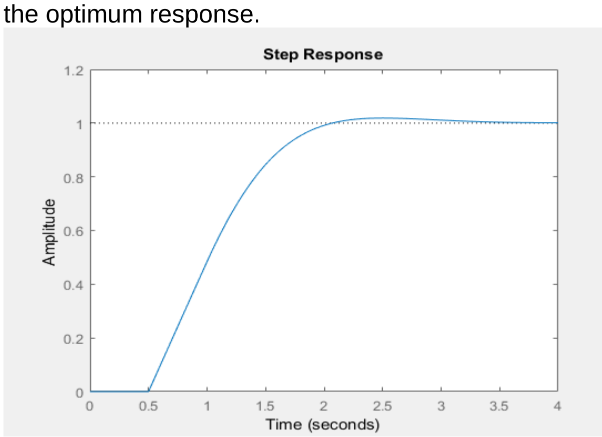

***Fig. 13**- Response of the Performance Parameter with PID controller*

In order to compare the performance of PID and PD like Fuzzy controller on the given plant, let us take a look at their different performance parameters to a unit step input.

***Table 7-** Parameter Values*

PID Controller parameter	Tuned Parameters
Kp	2.799
Ki	0.5001
Kd	3.9165
Rise time	1.02 Sec
Settling time	1.92 Sec
Overshoot	1.79%

Here the proportional gain is Kp,the integration coefficient is Ki and the derivative coefficient is Kd. The simulation results so obtained show that the PID controller gives low steady state error and setting time, thus high response. Hence alternative method like Fuzzy controller is needed for better performance.

5.3 Comparison between Fuzzy and PID controller:

Fuzzy controllers have the advantage that can deal with nonlinear systems and use the human operator knowledge. Here we tested it with a linear system of second order with known parameters. In order to compare it with one classical controller we simulated the same system controlled by PID. PID controller has only three parameters to adjust. Controlled system shows good results in terms of response time and precision when these parameters are well adjusted.
Fuzzy controller has a lot of parameters. The most important is to make a good choice of rule base and parameters of membership functions. When controller is given the entire framework can really be considered as a deterministic framework when the boundaries are all around picked the reaction of the framework has excellent time area attributes [6]. The fuzzy controlled system is very sensitive to the distribution of membership functions but not to the shape of membership functions. The given table shows the formation of response of the system when using PID & Fuzzy Logic controllers respectively by utilized in this cycle as a result of some reasons such as Fuzzy controllers have better stability, small overshoot and fast response [7].

***Table** 8- Compared with Fuzzy and PID controller*

S. no	Controller used	Rise time	Settling time	Overshoot
1	Fuzzy Logic Controller (from table-3)	12.951S	Undefined	0.505%
2	PID controller (From table 2)	1.02 Sec	1.92 Sec	1.79%

6. RESULTS AND DISCUSSIONS

Fuzzy control has risen one of the most dynamic and productive regions of examination particularly in mechanical cycles which don't depend upon the customary techniques as a result of absence of quantitative information with respect to the both output and input relations. For based on fuzzy logic which Fuzzy logic rules are simple and do not require precise control algorithm. Fuzzy logic systems are suitable for approximate reasoning. It's proved after comparing the graphs of conventional PID and fuzzy logic controller as shown in Table 8 it is clear that fuzzy logic has small overshoot and is having the fast response as compared to conventional PID Controller.

7. CONCLUSION

An analysis of the objective of this work is to make an investigation of the performances of a fuzzy controller and a relative investigation of fuzzy and conventional control approach corresponding in a case of the catalytic cracking process. The study is structured some parts such as the description of process and the structure of classical control with elaborated of the fuzzy logic control structure for the proposed process and the development steps of the controller. In the last aspect of the paper an exhibition investigation of the fuzzy logic and ordinary PID controller has been finished by the utilization of Matlab and Simulink and lastly by comparison of several time domain parameters has been performed to prove that the controller has quick response with small overshoot as compared to the PID controller. Better control performance, robustness and in general dependability can be normal from the fuzzy controller [8]. The results have clearly emphasized the advantages of fuzzy inference systems. 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.

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