PID Controller Tuning for Optimal Closed Loop Performance

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Abstract— **In any control application, that involve PID controller, proper tuning is very important aspect. In PID tuning, three parameter of PID controller is changed so as to have optimal closed loop performance. The conventional controller doesn't incorporate the human intelligence. So in proposed work, to embed some kind of intelligence in the PID controller, Fuzzy logic based auto tuned PID controller has been designed. Comparison with some of the previous work will show much better performance in terms of "Rise Time", "Settling Time", "Peak Overshoot", "Disturbance Rejection capacity". Proposed Fuzzy self tuned PID controller has much better performance as far as system robustness is concerned. In controller hardware design there is memory and computational constraints, i.e. computational time should be less as possible, so a designer needs to consider these two design aspects. This work addresses these key design challenges.**

Keywords—PID Controller,Fuzzy Logic,Matlab

I. INTRODUCTION

In most of the industrial Process control industry the PID(proportional-Integral-Derivative) controllers are widely used because of their simple structure ,easy designing method, clear functionality, easy understanding and robust performance over a wide range of operating conditions[1]. It has been known that PID controller is used in more than 90% of process control industry. If exact mathematical model of system to be controlled is not known, PID controllers are very effective. PID controller is a control loop feedback structure. Difference between measured process value and desired value (set-point) is said to be "error". It calculates "error" and tries to minimize this error by doing appropriate adjustment in the process input.

II. TUNING OF PID CONTROLLERS

PID controller is a control loop feedback structure. Difference between measured process value and desired value (set-point) is said to be "error". It calculates "error" and tries to minimize this error by doing appropriate adjustment in the process input. The PID controller has three different parameters; the proportional, the integral and derivative.

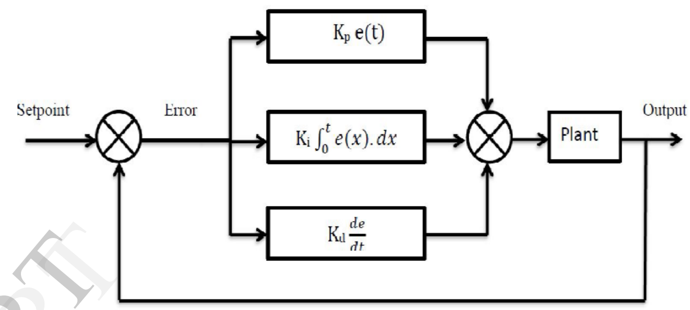

Figure 2.1 : Block diagram of PID Controller

Tuning of PID controllers has always been an area of intensive research in the process control industry. Ziegler Nichols Method (ZN) is one of the best and widely used methods of tuning available now [9]. It provides basic knowledge for PID Tuning. "Tuning" is the name given to adjustment of the three parameters of the PID controller so as to obtain desired or optimal closed loop performance. In the other words, Tuning optimizes any process by selecting appropriate value for three PID parameter. When Mathematical model of the system is known, the three parameters of the controller can be analytically determined. However, when a mathematical model is not known, the parameters are determined experimentally. The criteria for the optimal closed loop performance output will be:

(a) Rise Time
(b) Maximum Overshoot
(c) Stability
(d) Settling time
(e) Disturbance rejection capacity

III FUZZY SELF TUNING PID CONTROLLER

A. Fuzzy Logic Background

The Fuzzy Logic theory was introduced in 1965, by Lot fi Zadeh.

It is a mathematical tool for dealing with uncertainty in any system. It is a soft computing method which deals with words of human being. Fuzzy logic is a logic having which has much value rather than any exact value. Many values in binary logic reasoning is crisp whereas Fuzzy logic reasoning has vague boundary, or it can be said that it has approximate value. The variables in fuzzy logic indicate any value between 0 and1,so fuzzy logic system is able to deal the values of the variables those lies between completely truth and completely false. These variables are called linguistic variables; each linguistic variable is denoted by a membership function which has some degree of membership value at any instance. Fuzzy logic makes decision by embedding human knowledge into the system. [7]

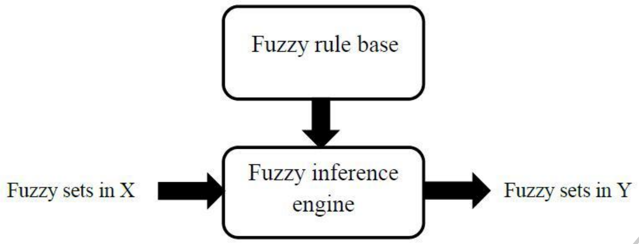

Fig 3.1: Fuzzy system

The fuzzy inference system in Fig. 3.1 takes fuzzy sets as input and produces output t fuzzy sets. The fuzzy rule base is called knowledge base of fuzzy system because it stores all rules of the system Fuzzy inference system make necessary decision necessary to produce a desired output."If-Then" rules are based upon human knowledge and experience

Fuzzy inference system is the important unit of a fuzzy logic system. In fuzzy logic decision making is an important part of the entire system. The fuzzy inference system makes appropriate rules. Based upon human knowledge and experience the rules are created. The fuzzy inference system makes "IF-THEN" statements and with the help of connectors present (such as OR), necessary decision are made. In most of the application, where a controller is used, it is required to have crisp or exact values of the output rather than fuzzy (vague) values. Therefore defuzzification is required, which converts the fuzzy values of Fuzzy inference system into corresponding crisp values.

There are three main types of fuzzy inference systems are used:

- Tsukamoto model
- Mamdani model,
- Sugeno model

Among these three Mamdani model is the most popular, and in this work same will be used.

There are three main type of defuzzification method:

- Mean of maximum
- Centroid of area
- Bisector of area

In our work, the "min and max" Mamdani system is used. "min and max" operators are used in place of "AND and OR" methods respectively.

The fuzzy rules for the system can be described as follows:
1. If" x is A1" and" y belongs to B1", then "z is C1".
2. If "x is A2" and "y belongs to B2", then "z is to C2".

The defuzzification method used is mean of maximum (MOM) method

B. Design of self tuning Fuzzy PID controller

The self tuning Fuzzy PID takes "error"(e) and "Rate of change of error"(ec) as input to fuzzy logic controller, and modify value of three PID parameter "Kp", "Ki" & "kd" online as output. Thus we have total of five linguistic variable (e,ec,Kp,Ki,Kd).Total of seven fuzzy value NB,NM,NS,ZO,PS,PM,PB are chosen for each of the linguistic variable**.** Which are short form of Negative big, Negative medium, Negative small, Zero, positive small, positive medium, positive big respectively. The region "e"and "ec" are between -3 to 3.whereas by doing some interpolation region of KP', Ki' & kd' are kept between 0 to 1.Interpolation tries to keep the value of the variable within specified region. The formula used are

$$Kp' = \frac{Kp - Kpmin}{Kpmax - Kpmin}$$

$$Ki' = \frac{Ki - kimin}{Kimax - Kimin}$$

$$Kd' = \frac{Kd - kd\ min}{Kdmax - Kdmin}$$

Where Kp', Ki', Kd' are previous value & Kp, Ki, Kd are modified new value. Suffix max and min are maximum and minimum value of variable that we take into our consideration

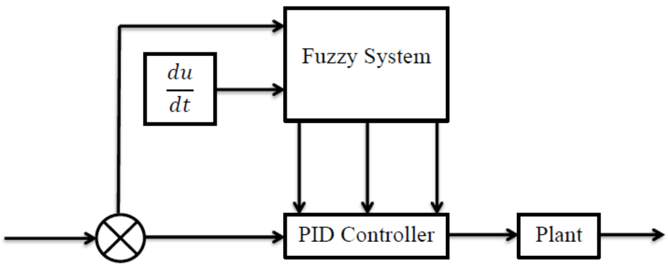

Fig 3.2: Basic Structure Of Fuzzy PID Controller

The linguistic rule is important part of Fuzzy Inference system. These rules are called the rule base. These rules are created with the help of human knowledge and expertise upon behaviour of the system under different condition .Any number of such rules can be formed to give the controller direction for action.

Rule Base for Kp

e/ec	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	NS	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NB	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table:3.1

Rule Base for Ki

e/ec	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

Table: 3.2

Rule Base for Kd

e/ec	NB	NM	NS	ZO	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

Table :3.3

Thus we have total of two input as "e' and "ec" and 3 output as "Kp", "Ki" &"Kd". Hence by these three tables total 49 rules are formed in FIS using MATLAB [4]. Rules can be formed like:

"If e is NB and ec is PB then Kp is ZO,Ki is ZO,Kd is PS"
"If e is NS and ec is PS then Kp is ZO,Ki is ZO,Kd is NS"
....
....

And so on............

IV-SYSTEM DESIGN

A. System Model: A continuous flow stirred tank

In chemical industry, it is cumbersome to test the mixing of Continuous flow stirred tanks [8] .Several tanks are cascaded .To maintain the concentration of the solute in these tank is daunting task. Now we consider a series of well-mixed vessels where the volumetric flow rate and the respective Volumes are constant.

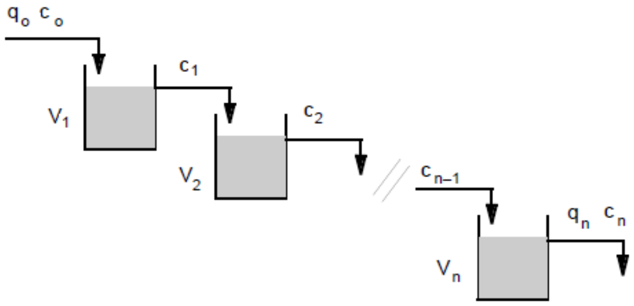

Figure 4.1:-"n" number of vessel in series

Where,
q0=inlet flow rate (cube-meter/s)
c1, c2, cn are concentration in gmol/cube-meter
v1, v2, vn are volume of solution
writing mass balance equation for first two tank

$$T1\frac{dc1}{dt}=C0-C1$$

$$T2\frac{dc2}{dt}=C1-C2$$

whereT1=v1/q0 and T2=v2/q0 are the space time for each veseel.Taking Laplace Transform of both the equation.

$$\frac{C1}{C0}=\frac{1}{T1S+1} \quad \text{and} \quad \frac{C2}{C1}=\frac{1}{T2S+1}$$

The effect of change in C0 on effluent in second vessel can be calculated as:

$$\frac{C2}{C0}=\frac{C2}{C1}*\frac{C1}{C0}=\frac{1}{T2S+1}*\frac{1}{T1s+1}$$

So For series of "n" Tank we can generalize the equation as follows

$$\frac{Cn}{Co}=\frac{1}{(T1s+1)(T2s+1)\ldots\ldots\ldots\ldots(Tns+1)}$$

Now, according to the value of "n", the order of equation will vary. we will take transfer function for PID tuning from here, in which concentration of effluent will be maintained.

We will discuss 3rd order system in which Ziegler Nicholas tuning will be applicable. The open loop transfer function(3rd order) describing our plant is as follows[1]:

$$G(s) = \frac{1}{(S+1)(S+3)(S+5)}$$

Which can be written in form of equation

$$G(s) = \frac{15}{(S+1)(.33S+1)(0.2S+1)}$$

B. Fuzzy Inference system design:

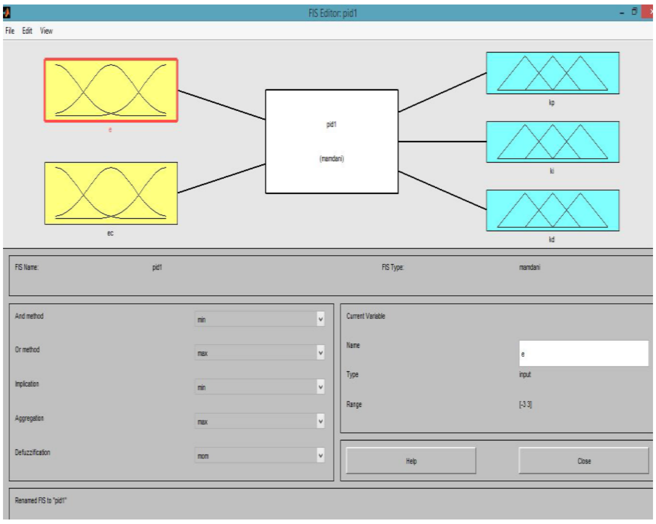

Fig 4.2: Two input three output FIS system

Two input three output Fuzzy Inference system (FIS) has been designed taking ‘error’ and ‘rate of change of error’ as input and three parameter (Kp, Ki &Kd) as output. The ranges “e”and “ec” are between -3 to 3.whereas by doing some interpolation region of Kp’,Ki’ & kd’ are kept between 0 to 1.It has been subject of great confusion that what should be the range for Kp,Ki and Kd,while designing Fuzzy Inference system. But in proposed work, by some interpolation the ranges are kept between 0 to 1.Here Triangular Membership function is used for its simplicity.

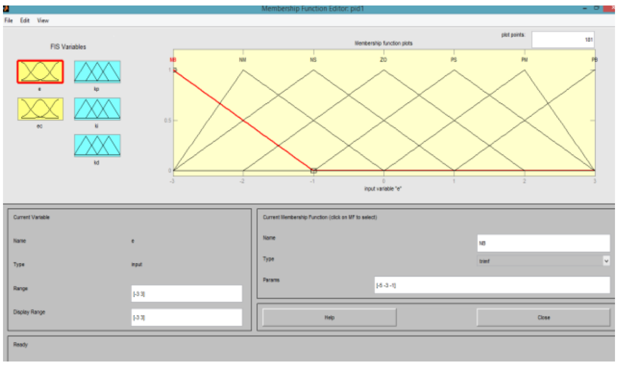

Fig 4.3-Menbership function

V. SIMULINK MODEL AND RESULT

A. System with no disturbance

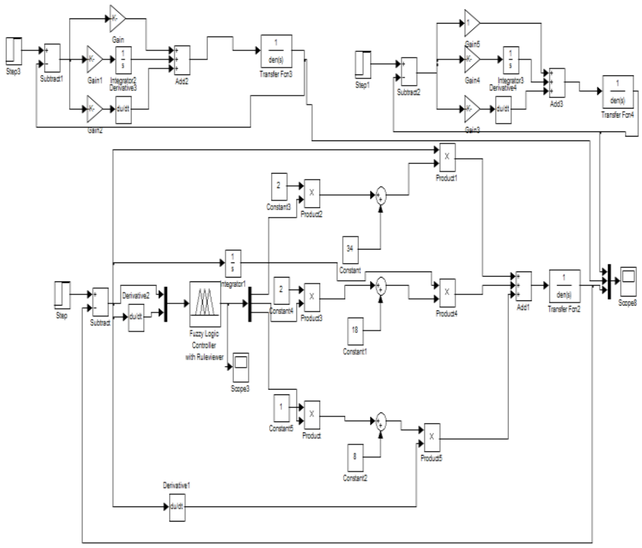

Fig.:5.1- Simulink Model

In figure 5.1 it can be seen a fuzzy logic controller has been used to tune the value of KP, Ki and Kd to get optimal closed loop performance. For interpolation, we first tune the PID controller using Ziegler Nicholas 2nd method [10]. It gives a educated guess for the range of the value of PID controller parameter. After several fine tuning we get the possible range for three parameter of PID controller.Matlab model in the fig has been designed according to this assertion.

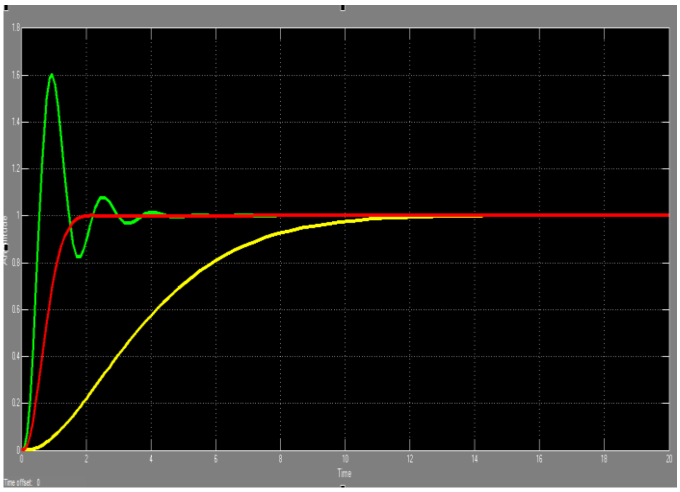

Fig: 5.2 –Output response

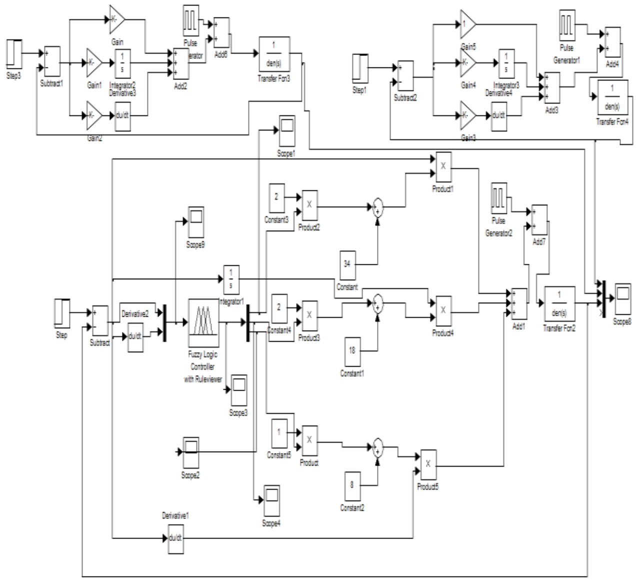

Fig 5.3: Simulink Model (with pulse Disturbance)

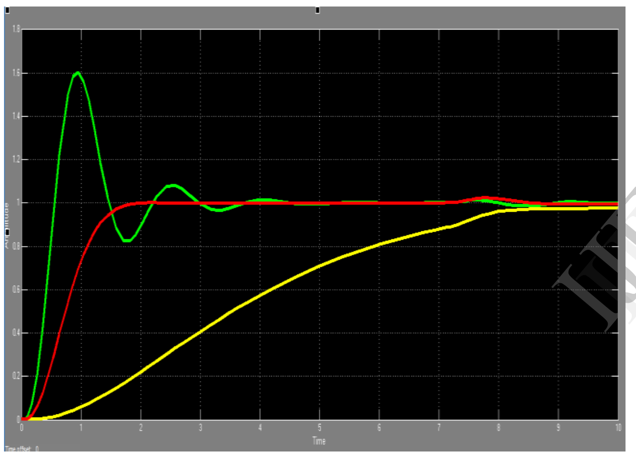

Fig 5.4: Output Response

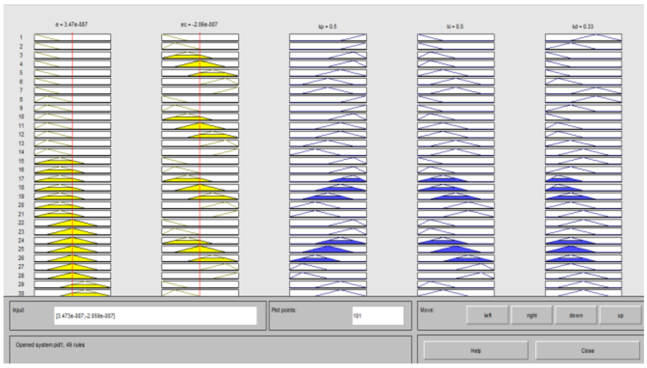

Fig 5.5: Rule viewer

VI. DISCUSSION OF RESULT

Result of this work is compared with two previous works, Ziegler Nicholas and model based approach of Salem [1]. For comparison purpose output response of all three are shown in single figure 5.2. It can be well observed that system response with PID controller tuned with Ziegler Nicholas method (Green) has large overshoot, whereas when tuned with the method of Salem (Yellow), it has large rise time. PID controller tuned with Fuzzy controller (Red) has acceptable rise time (< 2 sec), has no overshoot and smooth response with very less settling time. It can be also observed that if a disturbance(pulse with width of 10 sec and phase delay 7) is added into the system, it has negligible effect on system performance(fig 5.4).Comparison for all the three are given in the table 6.1

Tuning Method	Rise Time (Sec)	Maximum Overshoot	Settling Time(Sec)	Disturbance Rejection
Ziegler Nicholas	<1	60%	5	Good
Salem	12	No	13	Bad
Fuzzy Tuned	2	NO	2	Better

Table-6.1

VII. CONCLUSION

In this paper, tuning methods for PID controller using Fuzzy logic" has been discussed. A third-order chemical reactor plant was taken as the system, In which concentration of effluent in each of the vessel was to maintained at a fixed desired level. Simulation was carried out using MATLAB to get the output response of the system to a step input. The simulation results were observed and compared with that of some previous PID controller method in literature. As we observe the results, we find the use of above Fuzzy auto tuned PID control techniques giver better performance in terms of rise time, settling time, peak overshoot .It has smooth performance and good disturbance rejection capacity. The application of self tuning PID controller enable controller to tune itself while operating on-line, which makes system response faster.

VIII. FUTURE SCOPE

In future, for tuning of PID controller, some frequency response method could be adopted. We know that gain and phase margin is the two parameter that deals with the system robustness. It can be good research work, to tune PID controller when gain and phase margin has been specified

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