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Comparison of Various Tuning Methods for PID Controller for a CSTR System

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Abstract

In this paper, comparison of various tuning methods for PID controller has been done for a CSTR system. PID controller tuning has been done using Ziegler Nichols and fuzzy logic and also the operation of LQR has been implemented. CSTR plant was taken as the control object which has 2nd order transfer function. Simulation was carried out using MATLAB to get the output response of the system to a step input.The simulation results and the characteristics of both the methods were observed and compared with that of conventional PID controller. Finally, simulations are carried out to show the effectiveness of the fuzzy controllers with nested fuzzy if-then rules.

Keywords: *Continuous Stirred-Tank Reactor Model, Fuzzy Logic, Linear Quadratic controller, proportional-Integral-Derivative (PID), Simulation.*

1. Introduction

It is very important to control different parameters while operating with chemical process. The process may be exothermic or endothermic, while designing a controller, it is better to understand the process very well. An important part of process industry is the control of chemical processes by the help of various input variables classified as either manipulated or disturbance variables. A manipulated input is one that can be adjusted by the control system while a disturbance input is a variable that affects the process output.The major processes that needed to be controlled are level, thermal, gas etc. These are also, often the measured variables and are commonly the controlled variable. Different control loop demands different controllers, so the most important part of process control is to study the performance of the controller. Mathematical model of CSTR has been developed in **Kumar Narender** et al [1].After obtaining the transfer function of process and the transfer function of reference model a Mat Lab Simulink diagram is obtained. Design of a nonlinear feedback controller analyzed for temperature control of continuous stirred tank reactors (CSTRs) which have strong non linearities has been done in [2].The control objective in his simulation-based work is to maintain the CSTR at steady state operating point. Methodologies to learn and optimize fuzzy logic controller parameters based on neural network and genetic algorithm has been developed in [3].Designing of PID controller has been done in [4]. **Ziegler** et al [6] has proposed a system of units for measuring the control effects, which are now in common use. **Wang-Xiao Kan** et al [7] introduces a design method of fuzzy self-tuning PID controller and make use of MATLAB fuzzy toolbox to design fuzzy controller, organically combine fuzzy PID controller with Simulink. Development of a Linear Quadratic Regulator (LQR) for a set of time-varying hyperbolic PDEs coupled with a set of time-varying ODEs through the boundary has been discussed in [8]. **Qingsi Zhang**et al [9] uses Fuzzy logic controller with self-tuning PID parameter. CSTR system has been discussed in [10].

The aim of the paper is to compare the performances of various controllers for tuning of PID controller. The performance is evaluated in time domain with control using conventional controllers, using linear quadratic controller and using fuzzy logic controllers.

2. Basic Requirements

In order to control the process performance, we need a control system, which consists of a sensor, a controller and a final control element. Obviously, the sensor is a very important part of the control system. It monitors the process and serves as a signal source for the control system. In our previous discussion, we always assumed, there was some suitable measuring device available, but not all measuring devices can be used in automatic control. The basic requirements for a sensor used in a control loop are the abilities:

- to indicate the values of measured variables

The signals could be transmitted through either an electric circuit or a pneumatic pipeline; therefore, in order to transmit the signal, the sensors must have the ability to convert the measured variable values into either electric signals or pneumatic signals. The concept of the feedback loop to control the dynamic behavior of the system: this is negative feedback, because the sensed value is subtracted from the desired value to create the error signal, which is amplified by the controller.

3. PID controller Tuning Methods

3.1 Proportional Controller

Proportional action is the simplest and most commonly encountered of all continuous control modes. In this type of action, the controller produces an output signal which is proportional to the error. As the gain is increased the system responds faster to changes in set-point but becomes progressively oscillator and more oscillations means unstable. The proportional controller (Kp) reduces the rise time, increases the overshoot, and reduces the steady-state error.

3.2 Proportional and Derivative Controller

Derivative control is usually found in combination with proportional control, to form so-called P+D. By adding the derivative action, lead is added in the controller to compensate for lag around the loop, and so P+D can eliminate excessive oscillations. A disadvantage is that it cannot eliminate the offset although somehow it makes it smaller. When gain of the proportional controller is increased then stability and overshoot problems arise .This problem can be solved by adding a term proportional to the time-derivative of the error signal i.e. derivative controller.

3.3 Proportional and Derivative Controller

The integral controller (Ki) decreases the rise time, increases both the overshoot and the settling time, and eliminates the steady-state error.

3.4 Proportional, Derivative and Integral Controller

Although PD controls overshoot and ringing problems associated with proportional control but it does not solve the problem with the steady-state error. Fortunately it is possible to eliminate this while using relatively low gain by adding an integral term to the control function which becomes

$$u(t)=K[\, e(t)+ 1/Ti \int e(\tau)\, d\tau +Td\, de(t)/dt]$$

proportional controller (Kp) will reduce the rise time, but never eliminate, the steady-state error. An integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worse the response becomes more oscillatory and needs longer to settle, the error disappears.

4. Controller Tuning

Controller tuning involves the selection of the best values of kc, Ti and TD (if a PID algorithm is being used). This is often a subjective procedure and is certainly process dependent. **.** The most well-known tuning methods are those developed by Ziegler and Nichols. They have had a major influence on the practice of PID control for more than half a century. The methods are based on characterization of process dynamics by a few parameters and simple equations for the controller parameters.

4.1 Fuzzy Logic Controller

The concept of Fuzzy Logic (FL) was conceived by LotfiZadeh, a professor at the University of California at Berkley, and presented not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. This approach to set theory was not applied to control systems until the 70's due to insufficient small-computer capability prior to that time.

4.2 Linear Quadratic Controller

A system can be expressed in state variable form as

$$\dot{x} = Ax + Bu$$

With $(t)\epsilon R^n, u(t)\epsilon R^m$.The initial condition is x(0). We assume here that all the states are measurable and seek to find a state-variable feedback (SVFB) control.

$$u = -kx + v$$

that gives desirable closed-loop properties. The closed-loop system using this control becomes

$$\dot{x} = (A - Bk)x + Bv = A_c x + Bv$$

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with A_c the closed-loop plant matrix and v(t) the new command input. Output matrices C and D are not used in SVFB design.

5. Results and Discussions

The reactor transfer function is a second order system with right half plane (RHP) zero. The control objective is to keep the various performance specifications such as rise time tr, settling time ts, maximum overshoot Mp, maximum undershoot Mu and steady state error less within desirable limits. Fig.1 shows a proportional controller, the controller produces an output signal which is proportional to the error. Input used is step input.

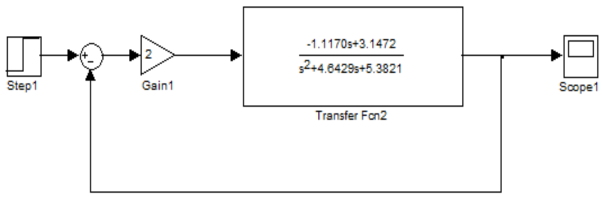

Fig.1 Simulink model of p controller

Fig.2 shows the response after using P controller. As the gain is increased the system responds faster to changes in set-point but becomes progressively oscillator and more oscillations means unstable. Fig.3 shows the response with various values of Kp.

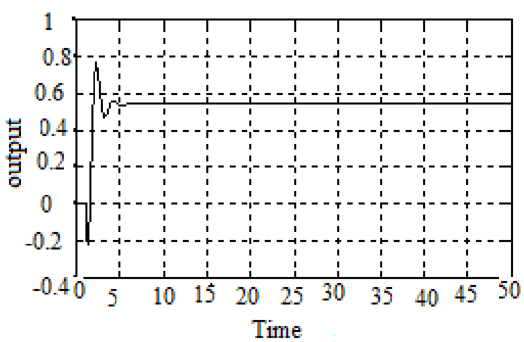

Fig.2 Output of P controller with K_p=2

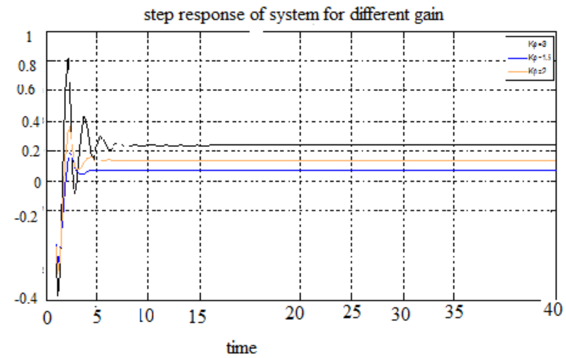

Fig 3 Output of P Controller with different gains

The integral controller (Ki) decreases the rise time, increases both the overshoot and the settling time, and eliminates the steady-state error. Fig.4 shows the system with PI controller.

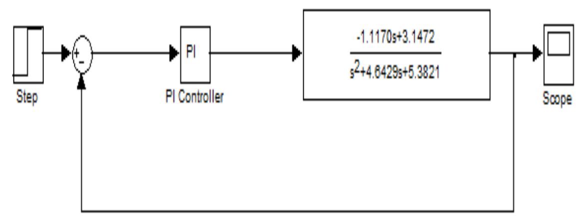

Fig.4 Simulink model of PI Controller

In fig.5 the response shows that the integral controller eliminated the steady-state error and the system becomes slower.

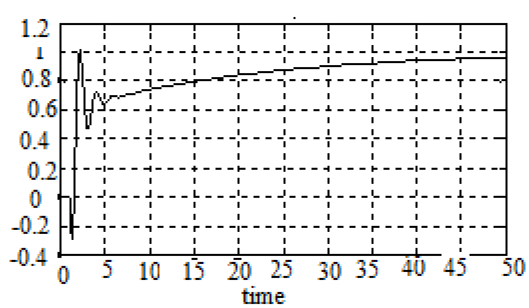

Fig.5 Output of PI Controller

To remove the steady state error we used PID controller. Simulink diagram of PID controller with kp = 3.54, ki =1.6 and k_d =0.4 is shown in Fig.6.

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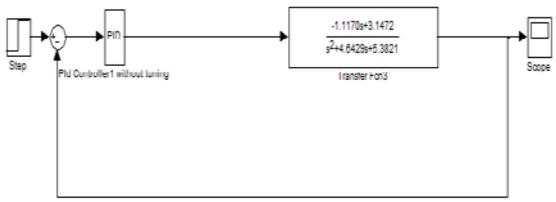

Fig 6 Simulink Model of PID controller

Output is shown in fig.7 the steady state error has been eliminated and response becomes faster.

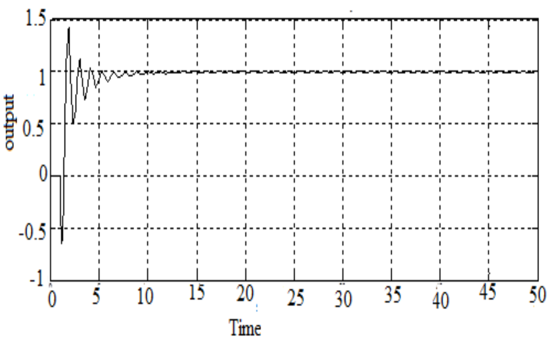

Fig.7 Output of PID Controller

Fig.8 shows Simulink diagram of PID controller after tuning using Ziegler Nichols method. Fig.9 shows that after tuning our response gets better but still the overshoot is present in the system.

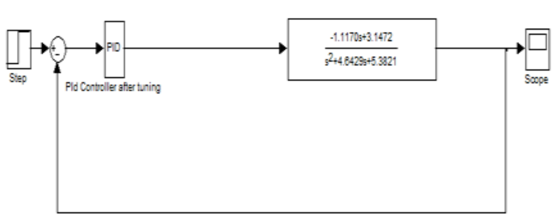

Fig.8 Simulink model of PID after tuning

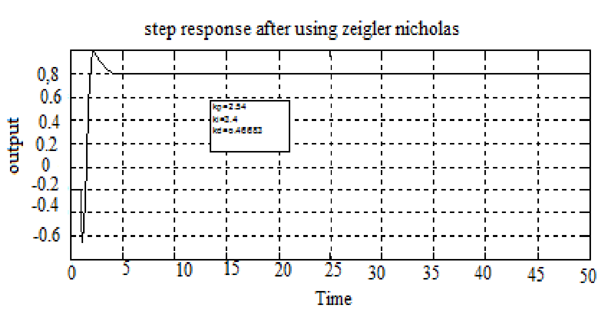

Fig.9: Output of PID after tuning

To make our response better fuzzy logic is used for tuning the controller. The Simulink model with fuzzy logic controller has been shown in fig.10. fig.11 shows the response using fuzzy logic controller which shows that overshoot has been completely eliminated and undershoot decreases.

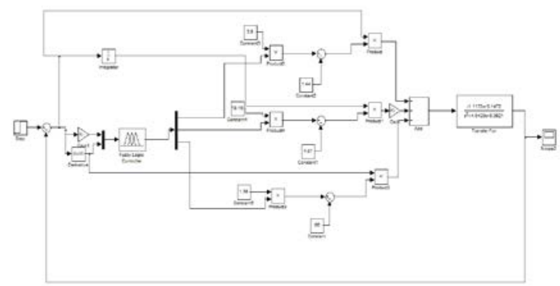

Fig.10 Simulink model with FLC

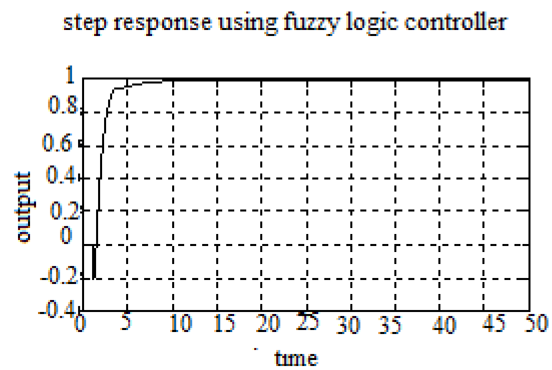

Fig.11OutputwithFLC

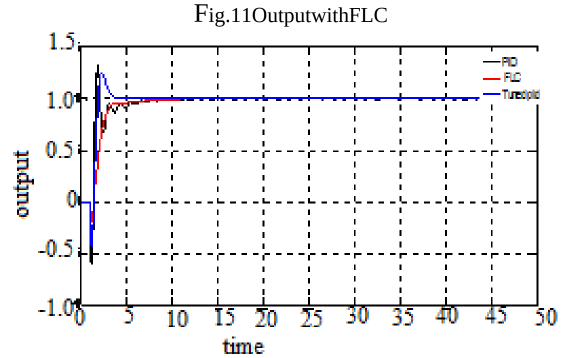

Fig.12 Comparison of PID, Tuned PID and FUZZY

In fig.12 the comparison of PID, Tuned PID and Fuzzy controller is shown. The graphs shows that when the controller is tuned using conventional methods the peak overshoot is still there and also the settling time is more but when it is tuned using fuzzy then the system response is improved. Another controller named LQR is also implemented and the results show that the response is much better than LQR.

PROGRAM

```
A = [-4.6429 -5.3821;1 0 ];
B = [1; 0];
C = [-1.1170  3.1472; 0 0];
D = [0;0 ];
P = 0.000001
Q = p*C'*C;
R = [0.01];
K = lqr(A,B,Q,R);
sys =ss(A, B, C, D);
SYS1= tf(sys)
[y t x]= step(sys);
sys_cl= ss(A-B*k,B,C,D)
step(1.6*sys_cl)
```

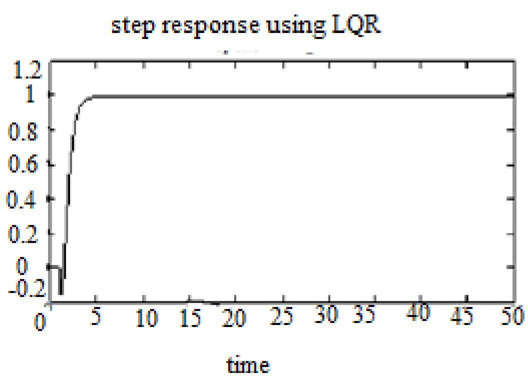

Fig.13 Output with LQR Controller

In fig.14 the response is shown for different value of R As soon as the value of R increases the amplitude increases.

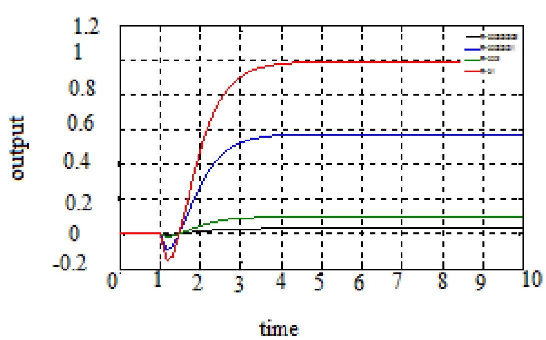

Fig.14 Output for different value of R

If we compare all the responses we conclude from fig.1 and fig.15, the problem of overshoot has been eliminated with FUZZY and LQR. The other characteristics values for comparison are shown in table1.

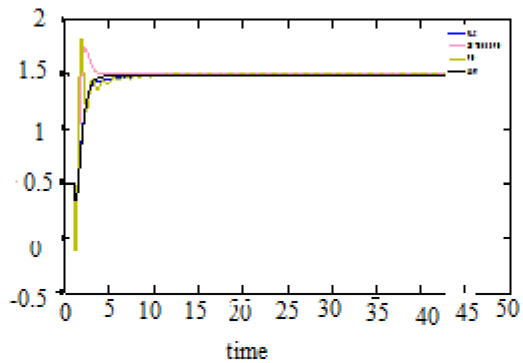

Fig.15 Comparison of all techniques

Table:1 Comparison of Different Parameter of Output

Parameter	*PID*	*Z-N PID*	*FUZZY*	*LQR*
Rise time	*2 sec*	*2 sec*	*2 sec*	*3 sec*
Settling time	*15 sec*	*4 sec*	*6 sec*	*5 sec*
Steady state error	*0.2*	*0*	*0*	*0*
Overshoot	*50%*	*20%*	*0*	*0*
Undershoot	*52%*	*42%*	*20%*	*20*

5. Conclusions

Comparison of various tuning methods for PID controller has been done for a CSTR system. PID controller tuning has been done using Ziegler Nichols and fuzzy logic and also the operation of LQR has been implemented. CSTR plant was taken as the control object which has 2nd order transfer function. Simulation was carried out using MATLAB to get the output response of the system to a step input. It is clearly observed from the results that use of soft computing technique for PID controller tuning results in better response with less overshoot and settling time. The application of fuzzy logic to the PID controller imparted the ability to tune itself while operating on-line.

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