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An Intelligent Design of PID Controller for a Continuous Stirred Tank Reactor

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Abstract: The proportional integral derivative (PID) controller is the most widely used control strategy in industry. The popularity of PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity. A Fuzzy logic controller using simple approach andsmaller rule set is proposed. Simulation results are demonstrated. Performance analysis shows the effectiveness of the proposed Fuzzy logic PID controller as compared to the ZN tuned PID controller and IMC PID controller. In this study, a design methodology is introduced that blends the classical PID and the fuzzy controllers in an intelligent way and thus a new intelligent hybrid controller has been achieved. Basically, in this design methodology, the classical PID and fuzzy controller have been combined by a blending mechanism that depends on a certain function of actuating error. Moreover, an intelligent switching scheme is induced on the lending mechanism that makes a decision upon the priority of the two controller parts; namely, the classical PID and the fuzzy constituents. CSTR is a highly non-linear process. The reactor has two uncertain parameters, the concentration and the temperature of the reacting mixture. The intelligent PID designed here is implemented for CSTR process and the results are compared with IMC PID controller and ZN-PID controller. The simulation is done in MATLAB SIMULINK.

Key words: Robust control · Continuous Stirred Tank Reactor (CSTR) · Internal Model Controller (IMC) · PID controller

INTRODUCTION

CSTR is a nonlinear chemical reactor widely used in chemical industry and can be simplified as an affine nonlinear system. Chemical reactors are ones of the most important plants in chemical industry. Their operation, however, is corrupted with various uncertainties. Some of them arise from varying or not exactly known parameters, as e.g. reaction rate constants, heat transfer coefficients. In other cases, operating points of reactors vary or reactor dynamics is affected by various changes of parameters or even instability of closed loop control systems. Application of robust control approach can be one of ways overcoming all these problems. In this project, a simple method for design of robust PID controllers and IMC is presented. The approach is used for design of a robust PID and IMC for the CSTR. The reactor has three uncertain parameters: the reaction enthalpy, the reaction rate constant and the overall heat transfer coefficient. The control input is volumetric flow rate of the coolant and the controlled output is the temperature of the reacting mixture.

PID controller [1-3] and Internal model controller (IMC) [4, 5] controller are the two most popular control schemes that have been widely implemented throughout the chemical process industries for the past two decades. However, control of nonlinear system using above linear control schemes doesn't give satisfactory performance at all operating points. The introduction of powerful nonlinear control [6] schemes such as Intelligent PID, the proposed control strategy, is necessary because it offers advantages such as simple design and low computational complexity. The conventional PID controller suffers [7] in transient state while fuzzy controller is unable to produce a constant steady state [8, 9]. So it is necessary to develop a new hybrid controller which accommodates the advantages of all conventional controllers and eliminates their drawbacks.

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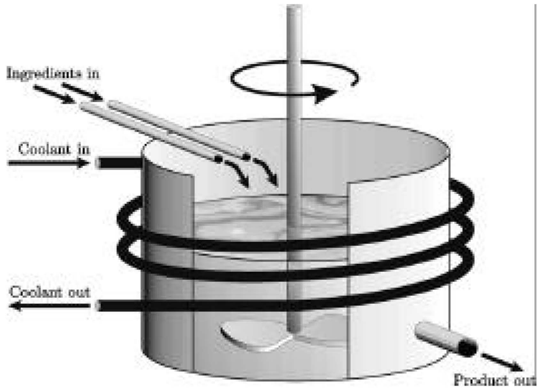

Fig. 1: CSTR process

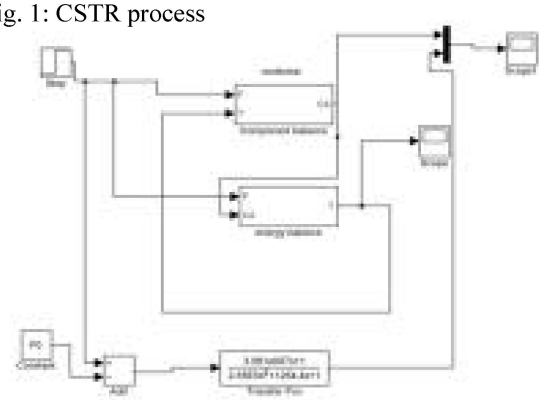

Fig. 2: Simulink Block for Nonlinear CSTR

The main contributions of this work are as follows; firstly, the nonlinear system is represented as a family of local linear models Secondly, local PID controllers and IMC controller has been used to control the nonlinear process and finally a Fuzzy PID control scheme using the family of local linear models has been proposed to control nonlinear process.

System Description: A chemical system common to many chemical processing plants, known as a continuous stirred tank reactor (CSTR), [10] was utilized as a suitable test for, TSK Fuzzy control, ANFIS control and PID control. It suffices to know that within the CSTR two chemicals are mixed and react to produce a product compound with concentration Ca (t). The temperature of the mixture is T (t).A schematic representation of the system is shown in Fig. 1. The reaction is exothermic, producing heat which acts to slow the reaction down. By introducing a coolant flow rate qc(t), the temperature can be varied and hence the product concentration controlled. This system can be described by the following nonlinear simultaneous differential equations ((1) and (2)) which effectively combine the laws of chemical reaction [2] and thermodynamics:

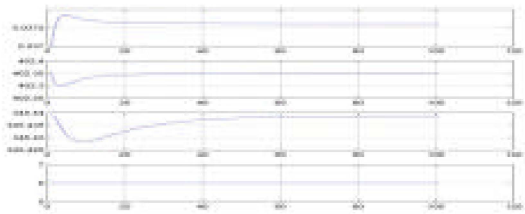

Fig. 3: Open loop response of CSTR for Initial conditions

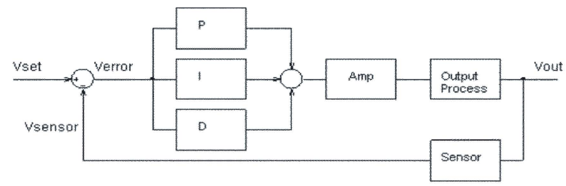

Fig.4. Block diagram of PID Controller

$$\dot{C}a(t)=Q(Ca0-Ca(t))/V-k0Ca(t)e-E/R\,\vartheta\,(t) \qquad (1)$$

$$\dot{T}(t)=Q(T0-T(t))/V+k_1Ca(t)e-E/RT(t)+k_2qc(t)-e-k_3/qc(t))(Tc0-T(t) \qquad (2)$$

This equation can be linearised as:
Which is a pseudo-first-order equation.
Similarly $\frac{\delta T}{\delta F}$ can be obtained

Pid Controller: The PID controller is also called as three mode controller. In industrial practice, it is commonly known as proportional-plus-reset-plus-rate controller. The combination of proportional, integral and derivative mode is one of the most powerful but complex controller operations. This system can be used for virtually any process condition. The equations of proportional mode, integral mode and derivative mode are combined to have analytic expression for PID mode,

$$U(s)/E(s) = K_p(1 + 1/T_is + T_ds) \qquad (4)$$

This mode eliminates the offset of the proportional mode and still provides fast response. The three adjustment parameter here is proportional gain, integral time and derivative time. The transfer function of PID controller is shown in (3). PID controller is the most complex of the conventional control mode combination. The PID controller can result in better control than [11] the one or two controller. In practice, control advantage can be difficult to achieve because of the difficulty of selecting the proper tuning parameters Fig 4 shows the parallel form P+I+D controller. The parameters of PID controller Kp, Ti, Td are tuned by Z-N procedure from the linear model of CSTR is as.

Fig. 5: Response of PID controller for Temperature

Fig. 6: PID controller response for concentration

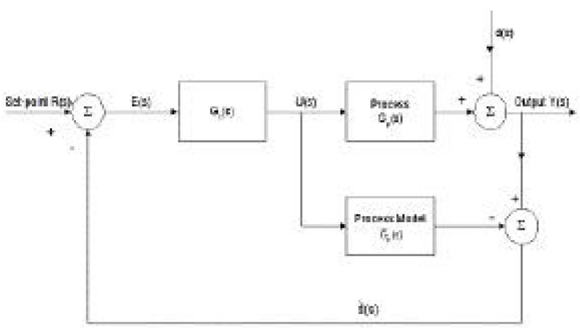

Fig. 7: Block diagram of IMC

Kp = 0.5; Ti = 0.2;Td = 0.0

Internal Model Principle (IMC): The IMC philosophy relies on the Internal Model Principle, which states that control can be achieved only if the control system encapsulates, either implicitly or explicitly, some representation of the process to be controlled. In particular, if the control scheme has been developed based on an exact model of the process, then perfect control is theoretically possible. The IMC strategy is the process may not be invertible and the system is often affected by unknown disturbances. It forms the basis for the development of a control strategy that has the potential to achieve perfect control. This strategy is known as IMC. Fig 7 shows the block diagram of IMC. The IMC structure is composed of the explicit model of

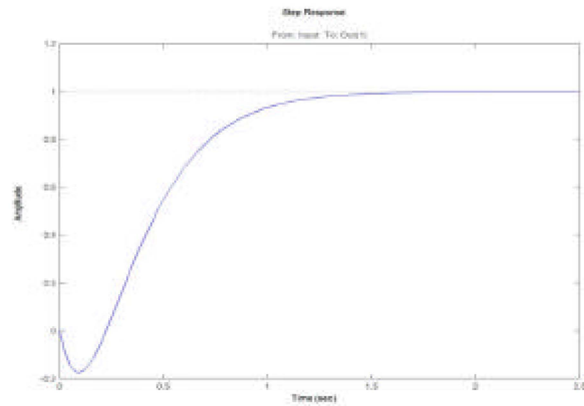

Fig. 8: Response of IMC for Concentration

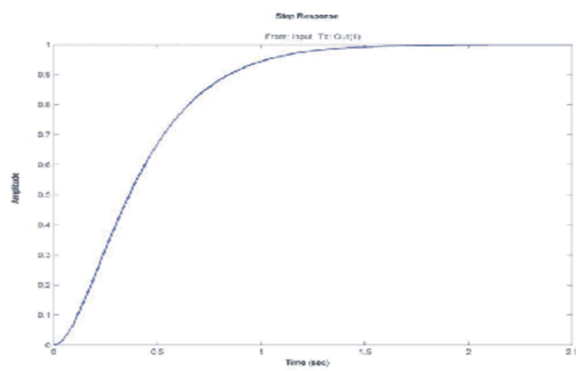

Fig. 9: Response of IMC for temperature

the plant and a stable feed forward controller. The IMC controller guarantees the internal stability of the closed loop and the parameters of the controller can be tuned online easily without affecting the stability of the system [12].

In the block diagram, d(s) is an unknown disturbance affecting the system. The manipulated input U(s) is introduced to both the process and its model. The process output, Y(s) is compared with the output of the model resulting in a signal d(s), that is.

$$d(s) = [Gp(s)-Gp(s)]U(s) + d(s)$$

The IMC scheme has the following properties,

- It provides time-delay compensation.
- The filter can be used to shape both the set point tracking and disturbance rejection responses.
- At the steady state, the controller will give offset free responses.

Fig 8 and Fig 9 shows the responses of IMC for concentration change and Temperature change of CSTR.These responses shows the elimination of steady state error and overshoot in PID responses.

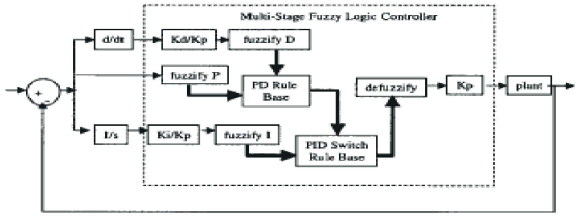

Fig . 10: Block Diagram of Fuzzy PID controller

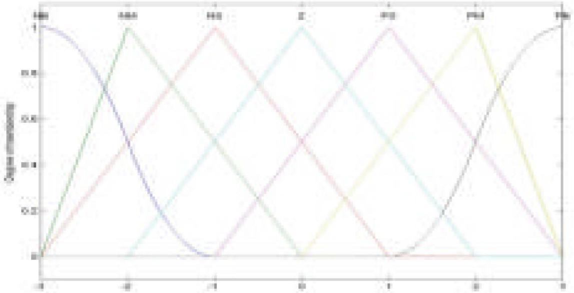

Fig. 11: Membership function for Change in Error

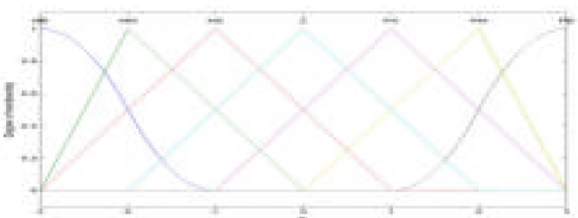

Fig. 12: Membership function for Error

Fuzzy Pid Controller: PID controller is still the most popular controller which is widely used to improve the performance of the hydraulic actuator in industry, because it's easy to operate and very robust. Latest PID controller's structure is quite different from the original one and the implementation is based on a digital design [13]. These digital PID include many algorithms to improve their performance, such as anti wind-up, auto-tuning, adaptive, fuzzy fine-tuning and Neural Networks [14-16]. However, the basic operations still remain the same. The performance specifications of the systems such as rise time, overshoot, settling time and error steady state can be improved by tuning value of parameters *Kp*, *Ki* and *Kd* of the PID controller, because each component has it's own special purposes.

It is straightforward to envisage a fuzzy PID controller with three input terms, error, integral error and derivative error. A rule base [7] with three inputs however becomes rather big and the rules concerning the integral action are troublesome. Therefore it is common to separate the integral action. A hybrid fuzzy PD + conventional I controller structure can be achieved by placing a Fuzzy PD controller in parallel with the conventional Integral controller [13, 17]. The structure of Fuzzy PID model is as shown in Fig. 10. For a two input fuzzy controller, 3, 5, 7, 9 or 11 membership functions for each input are mostly used [2]. In this work, only two fuzzy membership functions are used for the two inputs error e and derivative of error $\dot{e}$.The fuzzy linguistic rules are defined from the output response of the system. The PID controller parameters and the fuzzy gains in FPD + I controller are related in the following way:

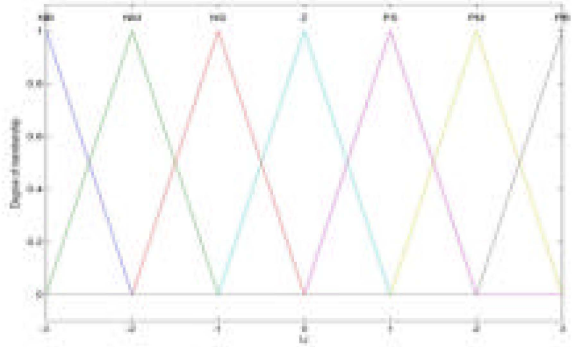

Fig. 13: Membership function for Output

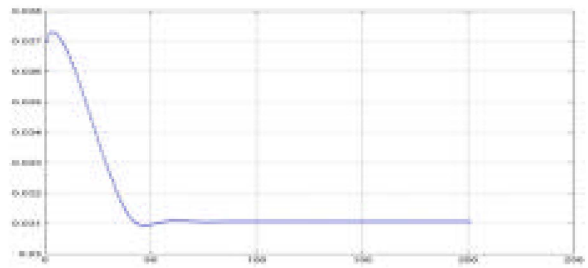

Fig. 14: Fuzzy PID controller response for Concentration control of CSTR

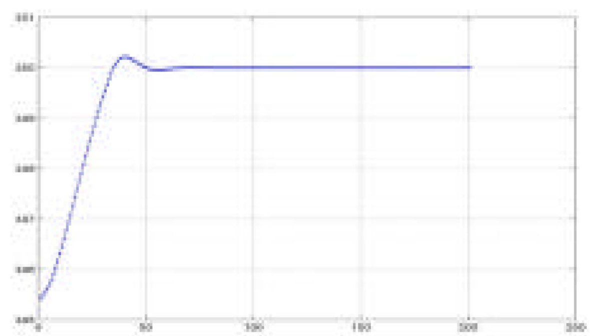

Fig. 15. FuzzyPID controller response for Temperature control of CSTR

$$GE \times GU = Kp, \quad GCE/GE = Td, \quad GIE/GE = 1/Ti$$

Fig 11 shows the membership function of change in error. There are seven linguistic variables are selected (NB,NM,NS,Z,PS,PM,PB) and the range is taken between -3 to 3.Triangular membership function is selected.

Fig 12 shows the membership function of error. There are seven linguistic variables are selected (NB, NM, NS, Z, PS, PM, PB) and the range is taken between -3 to 3.Triangular membership function is selected.

Fig 13 shows the membership function of controller output. There are seven linguistic variables are selected (NB, NM, NS, Z, PS, PM, PB) and the range is taken between -3 to 3.Triangular membership function is selected.

The Centroid method of defuzzification principle is used and implementation of this controller is by M file.

This work have described the controller design of a CSTR process using conventional technique and fuzzy PID.

By employing an appropriate procedure, the proposed process can refine fuzzy if-then rules obtained from human experts to describe the tuning of a nonlinear system. The learning process was started to generate a set of fuzzy if-then rules to approximate a desired data set. Results show that the performance obtained by this method is better than that used in other methods. The most advantage of using FPID is used to eliminate the transient errors and steady state errors in the process completely and to obtain a better output with less overshoot. Simulation of FPID configuration is carried out in MATLAB and its result is shown in Fig 14. The response in Fig. 8. and Fig. 14 are compared and tabulated in the below Table 1.

Table 2 shows the comparison between IMC and FPID controller indicates that the FPID controller implies better response in all aspects of time domain specification in steady state and transient state conditions.

Table 1: CSTR PARAMETERS

Parameter	Description	Nominal value
Q	Process flow rate	100 l/min
V	Reactor volume	100 l
k0	Reaction rate constant	7.2×10^{10} 1/min
E/R	Activation energy	1×10^4 K
θ_0	Feed temperature	350K
θ_{C0}	Inlet coolant temperature	350K
ΔH	Heat of reaction	-2×10^5 cal/mol
Cp, Cp_c	Specific heats	1 cal/gK
ρ, ρ_c	Liquid densities	1×10^3 g/l
Ca_0	Inlet feed concentration	1mol/l
h_a	Heat transfer coefficient	7×10^5 cal

Table 2: Comparison of IMC VS FPID

Time domain parameters	ZN-PID	IMC-PID	FPID
Rise time	3.1 s	0.0209 s	31.3008 ms
Settling time	7.2sec	47.9552 ms	56.5991ms
Overshoot	10	7.5310	6.1915e-004
Undershoot	1.8	9.5091e-012	1.1448
Peak time	50	49.3424	1.0395

CONCLUSION

Thus in this paper, Controller design is carried out by PID, IMC and FuzzyPID methods.

Our simulations show that the proposed method outperforms an optimally tuned PI controller. Despite the fact that the FPID performs similarly to a conventional PID controller, it should be noted that the PID controller uses all the information obtained from the process model and depends greatly on the canonical representation of the process model, whereas the FPID method relies simply on the input/output behavior (data) associated with the process. In order to show the ease of use and performance of the proposed method, it has been used to control the non-isothermal reactor at its optimum operating conditions. Simulation results show that despite its ease of use, the designed FPID controller performs quite well in both set-point tracking and load rejection problems.

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