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Design of Fractional Order PID controller for a CSTR process

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Abstract:- Continuous Stirred Tank Reactor (CSTR) sometimes involves complex reactions with high nonlinearity. To handle these problems, modern control strategy called Fractional Order PID controller has been reviewed. Fractional order controller is widely used in most areas of science and engineering, being recognized its ability to yield a superior control in many dynamical systems. For isothermal CSTR, FOPID controller is implemented to control a nonlinear process. This work proposes the applications of a Fractional Order PID (FOPID) controller in the area of Process Control for a CSTR Process to evaluate the use of Fractional Order PID controller with soft computing techniques. To design Fractional Order PID controller is to determine the two important parameters λ (integrator order) and μ (derivative order). In this article that the response and performance of Fractional Order PID controller is compared with closed loop conventional PID controller.

Keywords:- Conventional PID, CSTR process, FOPID, Genetic algorithm, PSO

I. INTRODUCTION

Reaction systems involving material recycles are very usual in process industry. There are several types of stirred reactors used in chemical or biochemical industry. CSTR is commonly used because of its technological parameters [1] [2]. Isothermal CSTR involves complex reactions with high nonlinearity. However their operation is corrupted with various uncertainties. Some of them arise from varying or not exactly known parameters such as 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. In general, PID controller produces long rise time when the overshoot in output response decreases. In order to tackle this problem and improve the dynamic response of CSTR process, a Fractional Order PID controller has been used. The design aspects of the controllers based on several soft computing techniques. A Fractional Order PID controller has been used to regulate the process parameters within a specified tolerance limit. A very important aspect of designing FOPID controllers is to decide upon the values of K_P, K_i, K_d, λ and μ. The Genetic algorithm and Particle Swarm Optimization Algorithms are used for tuning the FOPID controller. Fractional order dynamic systems and controllers have been increasing in interest in many areas of science and engineering in the last few years. Controllers consisting of fractional order derivatives and integrals have been used in industrial applications such as power electronics [3], system identification [4], robotic manipulators [5], etc., It should be noted that there are a growing number of physical systems whose behaviour can be compactly determined using the fractional order system theory and can be controlled with Fractional Order Proportional-Integral-Derivative (FOPID) controllers [6].

The present work deals with the design and control of a Continuous Stirred Tank Reactor process. The contribution of this work consists mainly in the design of K_P, K_i, K_d, λ and μ values are finding using Genetic algorithm and Particle swarm optimization technique to design the Fractional order PID controller and compared with conventional one. The development and implementation of the proposed controller was done using MATLAB/Simulink.

II. CONTINUOUS STIRRED TANK REACTOR PROCESS

The temperature control of a stirred-tank heater system is reported as a classical problem in chemical engineering. The complexity of the problem has been enhanced in the current study by changing simple tank to a reactor carrying out known reaction and also complete controller (both PID and FOPID) mechanism has been adopted. The analysis is extended further to stability of the system and optimization of the controller parameters along with a study on effect of reaction mechanism and other system parameters. The graphical diagram of the CSTR process is shown in Fig.1. A continuous stirred tank reactor with a non isothermal reaction A + B → Products and with first order rate equation ((-rA) = k CA) is considered. The tank has external heating coil with heat input Q (kJ/min) and the tank temperature is controlled by a controller in the closed loop feedback circuit as depicted in Figure 1. The temperature of the tank is measured at the outlet.

1. Modeling of Isothermal CSTR

The Continuous Stirred Tank Reactor with single input and single output is shown in Fig. 1. Here isothermal series-parallel reaction (Van der Vusse reaction) is considered to study the steady state and dynamic behaviour of CSTR. The two reactions are:

$$A \rightarrow B \rightarrow C$$
$$2A \rightarrow D \tag{1}$$

A – Cyclopentaddiene, B – Cyclopentenol, C – Cyclopentanediol, D – Dicyclopendtadiene

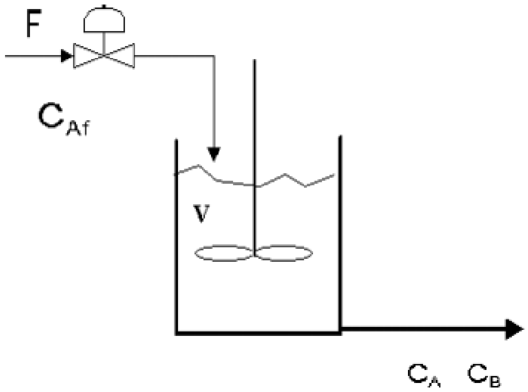

Figure 1: Isothermal CSTR

The desired product in the reaction is spices B, the intermediate product in the primary reaction, which increases the difficulty to control. The rates of formation of A and B are assumed to be:

$$r_A = -k_1 c_A - k_3 c_A{}^2 \tag{2}$$
$$r_B = k_1 c_A - k_2 c_B \tag{3}$$

Where k1, k2, k3are the reaction rate constants. The feed stream consists of pure A. The mass balances for A and B are given by the following Eq. (4) & (5):

$$\frac{d(C_A)}{dt} = \frac{F}{V}(C_{Af} - C_A) - K_1 C_A - K_3 C_A{}^2 \tag{4}$$
$$\frac{d(C_B)}{dt} = \frac{F}{V} C_B + K_1 C_A - K_2 C_B \tag{5}$$

The steady state equations are:

$$C_{As} = \frac{-\left(K_1 + \frac{F_s}{V}\right)}{2K_3} + \frac{\sqrt{\left(K_1 + \frac{F_s}{V}\right) + 4K_3\left(\frac{F_s}{V}\right)}}{2K_3} \tag{6}$$
$$C_{Bs} = \frac{K_1 C_{As}}{\frac{F_s}{V} + K_2} \tag{7}$$

These modelling equations assume a constant volume. The equations for C_C and C_D are neglected because C_B is not dependent on them. The manipulated input in this system is dilution rate. The parameters of the reactor are given in Table I.

Table I: CSTR parameters.

Parameter	**Value**
K_1	$50h^{-1}$
K_2	$100h^{-1}$
K_3	1/6 mol/liter min
C_{Af}	10gmol/liter

These results lead to the steady-state response of the CSTR as shown in the Fig. 2. For an isothermal CSTR steady state input-output can be obtained by relating dilution rate and concentration of component B.

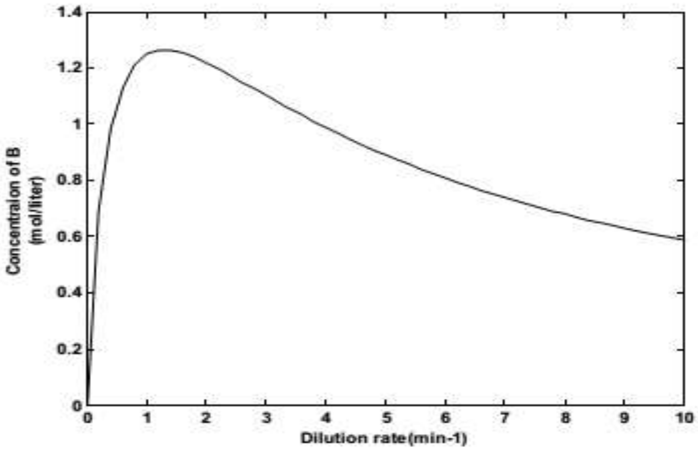

Fig. 2: Steady-State response of the CSTR

The Complexity involved in conventional modelling of CSTR increases due to the presence of nonlinearities like input multiplicity, gain sign change, asymmetric response and transformation from minimum to non- minimum phase behaviour and time lag in measuring instruments forcing to make many assumptions, sacrificing the accuracy due to the negligence of uncertainty. Inaccuracy in the modelling due to various assumptions gives degraded performance of controller. In the present work soft computing techniques are used to develop better and more efficient non linear model of CSTR.

III. FRACTIONAL ORDER $PI^{\lambda}D^{\mu}$ CONTROLLER

The most common form of a fractional order PID controller is the $PI^{\lambda}D^{\mu}$ controller involving an integrator of order λ and a differentiator of order μ where λ and μ can be any real numbers. The transfer function of such a controller has the form

$$G_C(s) = \frac{U(S)}{E(S)} = k_p + k_I \frac{1}{S^{\lambda}} + k_D S^{\mu}, (\lambda, \mu > 0) \tag{8}$$

Where *Gc(s)* is the transfer function of the controller, *E(s)* is an error, and *U(s)* is controller's output. The integrator term is $1\ s^{\lambda}$, that is to say, on a semi-logarithmic plane, there is a line having slope -20^{λ}dB/decade. The control signal u(t) can then be expressed in the time domain as

$$u(t) = k_p e(t) + k_I D^{-\lambda} e(t) + k_D D^{\mu} e(t) \tag{9}$$

Fig. 3 show the block-diagram configuration of FOPID. Clearly, selecting $\lambda = 1$ and $\mu = 1$, a classical PID controller can be recovered. The selections of $\lambda = 1$, $\mu = 0$, and $\lambda = 0$, $\mu = 1$ respectively corresponds conventional PI & PD controllers. All these classical types of PID controllers are the special cases of the fractional $PI^{\lambda}D^{\mu}$ controller given by (7).

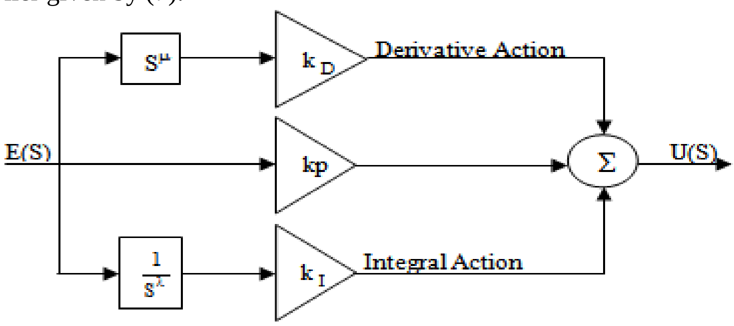

Fig. 3 Block diagram configuration of Fractional Order PID controller

It can be expected that the $PI^{\lambda}D^{\mu}$ controller may enhance the systems control performance. One of the most important advantages of the $PI^{\lambda}D^{\mu}$ controller is the better control of dynamical systems, which are described by fractional order mathematical models [8]. Another advantage lies in the fact that the $PI^{\lambda}D^{\mu}$ controllers are less sensitive to changes of parameters of a controlled system.

IV. GENETIC ALGORITHM

Evaluation of performance criteria is mainly based on measures of the system error. The system error is defined as the difference between the desired response of the system and its actual response. In the present work, GA based optimization technique is used to tune the PID and Fractional Order PID controller parameters minimizing the Integral Square Error. The technique uses genetic algorithm to tune the PID and FOPID parameters for a minimum performance index for each operating region of the CSTR process. The transfer function of the PID controller is given by

$$G_C(S) = K_C + K_I \frac{1}{S} + K_D \frac{d}{dt} \qquad (10)$$

V. PARTICLE SWARM OPTIMIZATION

PSO is an evolutionary computational technique based on the movement and intelligence of swarms looking for the most fertile feeding location. A "swarm" is an apparently disorganized collection (population) of moving individuals that tend to cluster together, while each individual seems to be moving in a random direction. PSO uses a number of agents (particles) that constitute a swarm moving around in the search space looking for the best solution [9-11]. Each particle is treated as a point in an n-dimensional space and adjusts its "flying" according to its own flying experience, as well as the flying experience of other particles. Each particle keeps track of its coordinates in the problem space, which are associated with the best solution (fitness) that has been achieved so far. This value is called *pbest.* Another best value called *gbest* is that obtained so far by any particle in the neighbours of the particle. The PSO concept consists of changing the velocity (or acceleration) of each particle toward its *pbest* and the *gbest* position at each time step. Each particle tries to modify its current position and velocity according to the distance between its current position and pbest, and the distance between its current position and the *gbest*. At each step n, by using the individual best position, pbest, and global best position, *gbest*, a new velocity for the i^{th} particle is updated by,

$$V_i = x(V_i(n-1) + \varphi_1 r_1 (pbest_i - P_i(n-1)) + \varphi_2 r_2 (gbest - P_i(n-1))) \qquad (11)$$

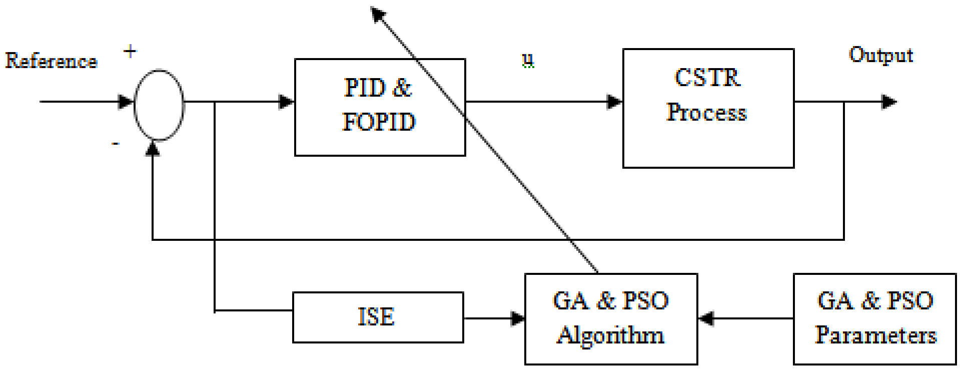

Fig. 4. Block diagram configuration of controller with soft computing techniques

VI. SIMULATION RESULTS

A controller is robust if it results in actual closed loop behavior that does not deviate unacceptably from the nominal closed-loop behavior which in turn, corresponds to nominal process behavior. The simulink model of the proposed system shown in Figs.5 and 6. The Nominal Response of proposed controller for CSTR process for step input, waveform for set point change of 20% increment and decrement at time period of 100 & 200 sec and waveform for line disturbance of 25% increment and decrement at time period of 100 & 200 sec are shown in Figs. 7,8 and 9 respectively. The Performance and analysis of CSTR process with PID and FOPID using GA and PSO algorithms shown in table II.

For isothermal CSTR nominal plant is given by

$$A_m = \begin{bmatrix} 0.78625 & 0 \\ 0.06607 & 0.79947 \end{bmatrix}$$

$$B_m = \begin{bmatrix} 0.62219 \\ -0.07506 \end{bmatrix}$$

$$C_m = \begin{bmatrix} 0 & 1 \end{bmatrix}$$

Transfer function model is given by

$$T.F = \frac{-0.0751z + 0.1001}{z^2 - 1.586z + 0.6286}$$

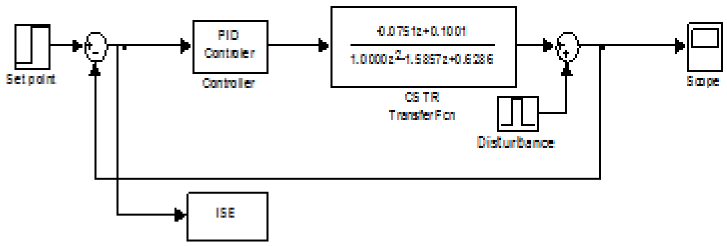

Fig. 5 Simulink of PID controller with CSTR Process

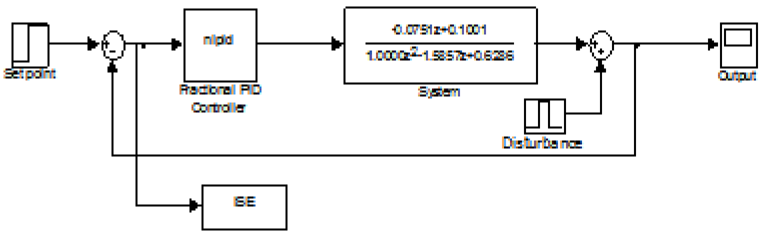

Fig.6. Simulink of FOPID controller with CSTR Process

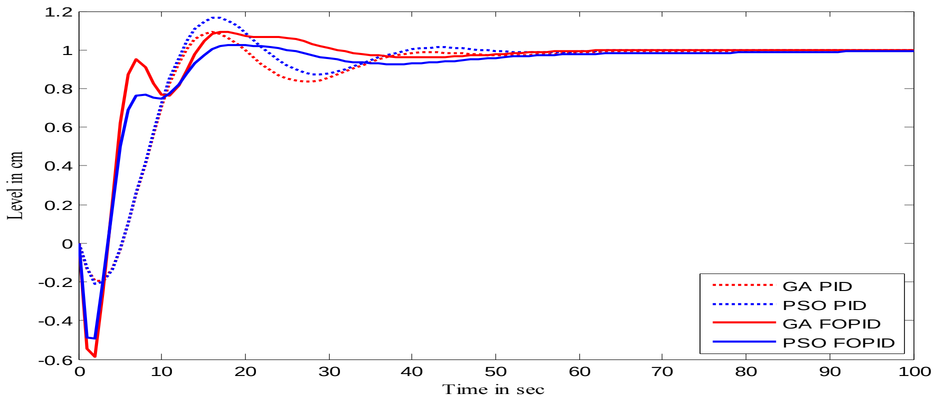

Fig.7. Nominal Response of proposed controller for CSTR process for step input

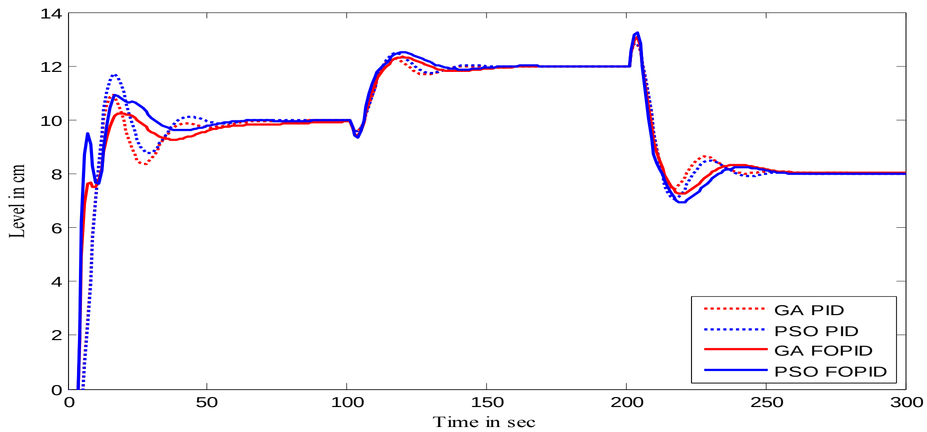

Fig.8. waveform for set point change of 20% increment and decrement at time period of 100 & 200 sec.

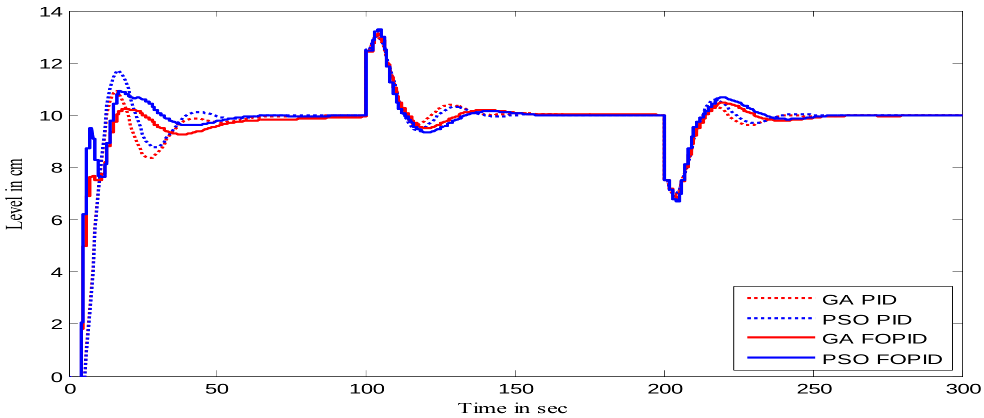

Fig.9. waveform for line disturbance of 25% increment and decrement at time period of 100 & 200 sec.

Table.II Performance and analysis of CSTR process with PID and FOPID using GA and PSO algorithms

CONTROLLER & ALGORITHM	Proportionality Gain (K_p)	Integral Gain (K_i)	Differential Gain (K_d)	Lamda (λ)	Mue (μ)	Cost (ISE)
GA PID	1.7552	0.1430	0.7833	-	-	9.8253
PSO PID	1.7114	0.1695	0.3766	-	-	9.7672
GA FOPID	0.0956	0.4089	1.6919	0.8570	0.2189	8.5528
PSO FOPID	0.7342	0.3816	0.7589	0.7967	0.3091	8.3371

VII. CONCLUSION

It is generally not possible to derive an accurate model of a process or plant especially with nonlinearities. If a reliable model is not available, it is quite difficult to design a controller producing desired outputs. When the data set does not represent the whole operating range adequately, the model to be obtained will not be as robust. Traditional modelling techniques are rather complex and time consuming when we incorporate entire dynamics of the process. However, soft computing techniques namely Genetic Algorithm and Particle Swarm Optimization have been used to obtain best model parameters. In the present work, modelling of CSTR was carried out using the above soft computing techniques. The model formulated captures the nonlinearity present in the CSTR. The model thus developed can be used in designing model based control schemes, such as PID and FOPID controllers which offers robust controller performance.

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