Particle Swarm Optimized I-PD Controller for Second Order Time Delayed System

S. J. Suji Prasad, Susan Varghese, P. A. Balakrishnan

Abstract— **In this paper, I-PD controller is optimized using particle swarm intelligence for a Second Order Time Delayed System. Optimization is done on the basis of performance indices like settling time, rise time, peak overshoot, ISE (integral square error) and IAE (integral absolute error). In industrial processes, PID controllers and its variants are most preferred though there are significant developments in the control systems. If the parameter of controller is not properly designed, then desired control output may fail. The simulation results with optimized I-PD controller proved to be giving better performances compared with Ziegler Nichols and Arvanitis tuning.**

Index Terms— **Proportional integral and derivative (PID); Proportional kick; Derivative kick; Settling time; Rise time and Tuning.**

I. INTRODUCTION

In industrial applications, PID controllers and its variants are most widely used, although there are advanced controllers, since they are able to compensate most practical industrial processes [1]. The desired process output can be obtained by adjusting three parameters of the PID controller. Different tuning rules for PID controllers reflect the upsurge of interest in the use of PID controllers. Other than conventional tuning methods, Evolutionary optimization techniques like GA (Genetic Algorithm), PSO, BF (Bacterial Foraging), ACO (Ant Colony Optimization) are widely used for optimizing the controller parameters.[2]

In the conventional PID controller, the proportional, integral and derivative actions on error are placed in the forward path. The proportional or derivative action on the error cause an abrupt change in the controller output when the set point change is introduced. This one is the addressed drawbacks of conventional PID controller [3]. This proportional and derivative kick can be avoided by I-PD controller where the proportional and derivative terms are given in the feedback path to avoid the set point kick. In this paper parameters of I-PD controller for a second order time delayed system are optimized using Particle Swarm Intelligence.

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II. I-PD CONTROLLER

In I-PD controller, the Proportional and Derivative term of the controller is given in the feedback path and Integral term in the forward path. So that the proportional and derivative action is applied on the process variable y(t).At the same time the integral action is given to the error e(t). The error is the difference between the set point or the reference input r(t) and the measured process variable y(t). Here the u(t) is the output of the controller and the input to the process.

The output of I-PD controller is given by

$$u(t) = K_p\left(\frac{1}{\tau_i}\int e(t)dt - (y(t) + \tau_d \frac{dy(t)}{dt})\right) \qquad (1)$$

where, K_p-controller derivative gain

τ_i -Integral time and

τ_d -derivative time respectively.

Whenever there is a change in set point change of the process, the error at that time may be high. In PID controller the proportional and derivative action gives an impulse signal or a sudden change in the controller output as it is fed by error signal. This spike in the controller output is called *proportional or derivative kick*. These kicks create serious problems for the electronic circuits which are driving the actuators like motor or valve. I-PD controller structure removes the proportional and derivative kick due the proportional and derivation of the error during set point change. [4]

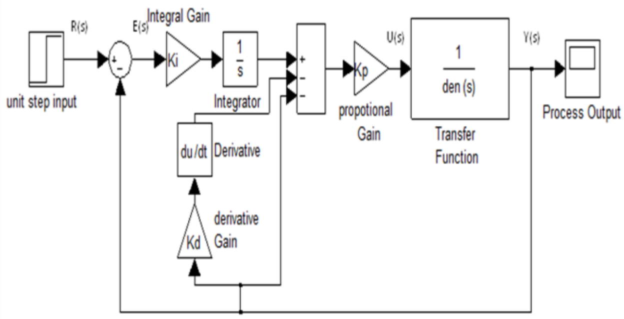

Fig. 1 Block diagram of the I-PD controller applied to a process

The Laplace transform of equation (1) is

$$U(s) = K_p\left[\left(\frac{1}{\tau_i s}\right)E(s) - [\tau_d s + 1]Y(s)\ \right] \tag{2}$$

Fig. 1 shows the block diagram of the I-PD controller applied to a process.

III. SECOND ORDER TIME DELAYED SYSTEM

Most of the process may have time delay. One of the time delayed model have been taken analysis in this paper [5].

The general form of a Second Order Time Delayed System is given by

$$G_m(s) = \frac{K_m e^{-s\tau_m}}{(1+T_{m1}S)(1+T_{m2}S)} = \frac{K_m e^{-s\tau_m}}{T_{m1}{}^2 S^2 + 2\zeta_m T_{m1} S + 1} \tag{3}$$

where K_m is the gain of the process model, τ_m is the time delay of the process model, ζ_m is the damping factor of an under damped process model and T_{m1} is the time constant of the process model.

The system analyzed is given by

$$G_{m1}(s) = \frac{e^{-0.1s}}{(1+S)(1+S)} = \frac{e^{-0.1s}}{S^2 + 2S + 1} \tag{4}$$

IV. CONVENTIONAL TUNING

A Ziegler-Nichols Tuning Rule

ZN method is widely used in PID controller tuning though it is an old tuning method . Its efficiency and simplicity made this method very popular. At the cross over frequency ω_c, M is the amplitude ratio of the system. The ultimate gain is Ku=1/M; and the period of sustained oscillations is Pu=2*pi/ ω_c. The PID controller parameters are calculated as

K_p =0.6Ku,

τ_i =0.5Pu and

τ_d =0.125Pu.

B Arvanitis Tuning Rule

Tuning rule proposed by Arvanitis for I-PD controller for different process model can be found by direct synthesis. For the tuning of I-PD controller, this rule uses model parameters like gain of the process, time constant, time delay constant and damping factor. [5]

The controller parameters for Second Order Time Delayed System are calculated by tuning rule is given in Table I

Table I Arvanitis Tuning Rule

K_p	τ_i	τ_d
$\frac{AT_{m1}}{K_m\tau_m}$	$\frac{K_pK_m}{\frac{1}{\tau_m}[1+B]-C}$	$\frac{T_{m1}}{A}$

where

$$A = \varepsilon\left[2\zeta_m + \frac{T_{m1}}{\tau_m}\right], \quad 0 < \varepsilon < 1, \varepsilon = 0.5 \tag{5}$$

$$B = \frac{T_{m1}(2\zeta_m\tau_m + T_{m1})[4\zeta^2(1-\varepsilon)+\varepsilon)}{\tau_m^2} \tag{6}$$

$$C = \frac{\zeta}{\tau_m^2}\sqrt{8(1-\varepsilon)(2\zeta_m\tau_m + T_{m1})\frac{T_{m1}}{\tau_m}\left[(2\zeta^2(1-\varepsilon)+\varepsilon)\frac{T_{m1}}{\tau_m}(2\zeta_m\tau_m + T_{m1}) + \tau_m\right]} \tag{7}$$

The values of controller parameters for process model (4) using ZN method and Arvanitis tuning rule are obtained and given in Table II

Table II Controller Parameters from Ziegler-Nichols and Arvanitis Tuning Rule

Controller Parameters	$\frac{e^{-0.1s}}{S^2+2S+1}$	
	ZN	Arvanitis
K_p	12.4026	60
τ_i sec	0.7083	0.9606
τ_d sec	0.1771	0.1667

V. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is one of the relatively recent evolutionary optimization method inspired by nature. This heuristic search method is based on social interaction and communication such as bird flocking and fish schooling. [6]

The direction of movement of the swarm is a function of Current position and Velocity, Location of individual's "best" success and Location of neighbor's "best" success. Therefore, each individual in a population will gradually move towards the "better" areas of the problem space. Hence, the overall population moves towards "better" areas of the multi dimensional problem space. The particle swarm is more than just a collection of particles. A particle by itself has almost no power to solve any problem; progress occurs only when the particles interact.[7]

Mainly there are three steps in basic PSO algorithm. These steps can be represented by the following equation

Initialization

Position $x_0^i = x_{min}$+rand *(x_{max}-x_{min}) (8)

Velocity v_0^i = 0.1*randn (dim, n) (9)

Where

x_{max}& x_{min} - boundary of the position

dim - dimension of the design space

n - no of particles

Velocity updation

$v_{k+1}^i = w{*}v_k^i + c_1{*}\text{rand}(\,).{*}(p_i - x_k^i) + c_2{*}\text{rand}(\,).{*}(p_k^g - x_k^i)$ (10)

where

w - inertia factor (in between 0.4 & 1.4)

c_1 - self confidence of the particle

c_2 - swarm confidence (in between 1 and 2)

p_i , p_k^g are the personal best and global best

Position updation

$$x_{k+1}^{i} = x_k^{i} + v_{k+1}^{i} \quad (11)$$

In the optimization of I-PD controller parameters, each particle represents a set of controller parameter in the problem space. That means position of a particle in three dimensional problem spaces is having a specific value of K_p, τ_i and τ_d.

To start with PSO certain parameters need to be defined. The parameters used here is given below

Size of the Swarm or no of particles = 30

No of iterations = 30

Dimension of the problem space = 3

Velocity constants C_1 and C_2 = 1.5

Inertia factor = 1

In PSO algorithm, each particle refers to a point in the design space or the potential solutions in the problem space which changes its position from one move (iteration) to another based on velocity update. The velocity updating is based on fitness of the particle's personal best and swarm's global best. While coming in to the optimization of controller parameters, each particle represents a set of K_p, τ_i, τ_d values in a three dimensional problem space. Commonly used minimizing functions to evaluate the fitness are IAE (Integral Absolute Error), ISE (Integral Square Error), MSE (Mean Square Error), settling time and peak overshoot.

In this paper settling time with 2% tolerance is used as the cost function. The optimization process finds the controller parameters that will minimize the cost function. So optimized set of controller parameters give the fast settling of the process response.

The Table III shows the results of Particle swarm optimization

Table III Controller Parameters from Particle swarm optimization

Controller Parameters	Particle Swarm $\frac{e^{-0.1s}}{S^2+2S+1}$
K_p	19.5928
τ_i sec	0.6934
τ_d sec	0.2295

VI. RESULTS AND DISCUSSION

It is observed from the step response of the Second Order Time Delayed System with I-PD controller, the controller parameters obtained from particle Swarm Optimization gives the better result compared to Ziegler-Nichols and Arvanitis Tuning rule.

The Fig. 3 shows step response of Second Order Time Delayed System process with I-PD controller Particle swarm optimized controller response give 66% reduced settling time, 10% reduced rise time, 88% reduced peak overshoot, 56% reduced IAE, and 58% reduced ISE compared to ZN. Table IV shows the performance comparison of the different tuning methods.

Table IV Performance Comparison Different Tuning Methods

PERFORMANCE SPECIFICATION	ZN	Arvanitis	**PSO**
Settling time (sec)	3.76	3.16	**1.26**
Rise time (sec)	0.79	0.78	**0.71**
Peak overshoot %	13.13	0	**1.59**
IAE	2.2228	1.4616	**0.9660**
ISE	0.0223	0.014	**0.0094**

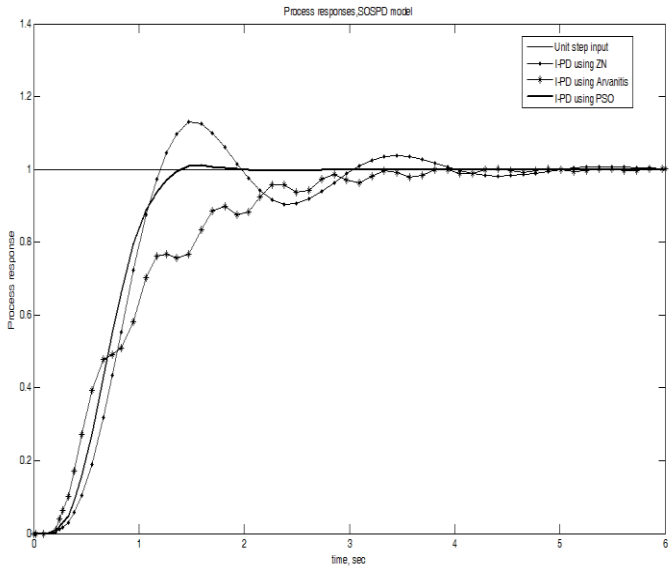

Fig.3 Output Response of the Second Order Time Delayed System

VII. CONCLUSION

Particle swarm optimized I-PD controller is implemented in a theoretical Second Order Time Delayed System. The process response shows significant reduction in settling time, rise time, peak overshoot, IAE, and ISE compared to ZN and Arvanitis tuning method.

PSO technique can be extended to optimize the parameters of I-PD controller for real time industrial systems like conveyors feeding systems, molding systems, water treatment systems and screwing systems.

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