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Craziness Particle Swarm Optimization based FOPI Controller for liquid level control of HCT

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ABSTRACT

Swarm intelligence techniques are offers an optimal or suboptimal solution to multidimensional rough objective functions. This work proposed the Fractional Order PI controller to control the level of horizontal cylindrical tank(HCT). Craziness Particle Swarm Optimization technique is used for designing PI and Fractional Order PI controllers that give better performance than their integer order controller. The response time, steady state error, load disturbance, and control valve action of the tank system are tested and compared with the conventional controller. The control valve action of the FOPI controller has operation high frequency than the conventional PI controller so the water level in horizontal tank is smoothly constant. Results show that this design method can effectively tune the parameters of the fractional order controller.
Keywords : CZPSO, FOPID, Horizontal Cylindrical tank (HCT), PI Controller.

I. INTRODUCTION

Proportional plus Integral (PI) controllers are widely being used in industries for process control applications. The merit of using PI controllers lie in its simplicity of design and good performance including low percentage overshoot and small settling time for slow industrial processes. The performance of PI controllers can be further improved by appropriate settings of fractional-I action. This paper attempts to study the behavior of fractional order PI controllers over integer order PID controllers for the proposed horizontal cylindrical tank system.

In a fractional PI controller, the I- and D-actions being fractional have wider scope of design. Naturally, besides setting the proportional and integral constants K_P and T_i respectively, we have two more parameters: the power of 's' in integral and derivative actions λ and μ respectively. Finding $[K_P, T_i, \lambda]$ as an optimal solution to the proposed tank process thus calls for optimization on the five-dimensional space. Classical optimization techniques cannot be used here because of the roughness of the objective function surface. Therefore it use a derivative-free optimization, guided by the collective behavior of social swarm and determine optimal settings of K_P, T_i and λ. The performance of the fractional PI controller is better than its integer controller. Thus the proposed design will find extensive applications in real industrial processes. Traces of work on fractional PI are available in the current literature [1]–[9] on control engineering. A frequency domain approach based on the expected crossover frequency and phase margin is mentioned in [2]. A method based on pole distribution of the characteristic equation in the complex plane was proposed in [5]. A state-space design method based on feedback poles placement can be viewed in [6].

The fractional controller can also be designed by cascading a proper fractional unit to an integer-order controller. Our design focuses on positioning closed loop dominant poles, and the constraints thus obtained on the characteristic equation are optimally satisfied by particle swarm optimization algorithm.

The present work deals with the design and control of a horizontal cylindrical tank system. The contribution of this work consists mainly in the design of K_P, K_i, and λ values are finding using Particle swarm optimization technique to design the Fractional order PI controller and compared with conventional one. The development and implementation of the proposed system and controllers was done using MATLAB/Simulink.

II. Fractional Order Controller

Fractional order calculus is an area where the mathematicians deal with derivatives and integrals from non-integer orders. There are different definitions of Fractional Order differentiations and integrations. Some of the definitions extend directly from integer-order calculus. The well-established definitions include the Grünwald-Letnikov definition, the Cauchy integral formula, the Caputo definition and the Riemann-Liouville definition [1, 60-62].

Controlling industrial plants requires satisfaction of wide range of specification. So, wide ranges of techniques are needed. Mostly for industrial applications, integer order controllers are used for controlling purpose. Now day's fractional order (FOPI) controller is used for industrial application to improve the system control performances. The most common form of a fractional order PI controller is the PI^{λ} controller [50]. FOPI controller provides extra degree of freedom for not only the need of design controller gains (K_P, K_i) but also design orders of integral and derivative. The orders of integral and derivative are not necessarily integer, but any real numbers.

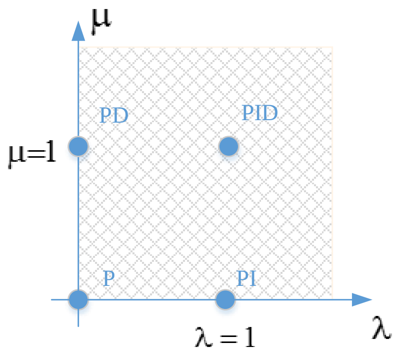

Fig.1. General Form of a fractional order PID controller

As shown in Fig.1, The FOPID controller generalizes the conventional integer order PID controller and expands it from point to plane. This expansion could provide much more flexibility in PID control design. The transfer function of such a controller has the following form [23].

$$G_C(S) = K_p + \frac{K_i}{S^{\lambda}} + \qquad (1)$$

It is Clear, by selecting λ = 1 and μ = 1, a classical PID controller can be recovered. Using λ = 1 and λ = 0respectively corresponds to the conventional PI & PD controllers. All these classical types of PID controllers are special cases of the $PI^{\lambda}D^{\mu}$ controller.

The most common form of a fractional order PI controller is the PI^{λ} controller [50], involving an integrator of order λ where λ can be any real numbers. The transfer function of such a controller has the form

$$G_c(S) = \frac{U(S)}{E(S)} = k_p + k_1 \frac{1}{S^{\lambda}}, (\lambda > 0) \qquad (2)$$

Where $G_c(S)$ is the transfer function of the controller, E(S) is an error, and U(S) is controller's output. The integrator term is $1s^{\lambda}$, 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

$$u(t) = k_p e(t) + k_i D^{-\lambda} e(t) \tag{3}$$

All these classical types of PI controllers are the special cases of the fractional PI^{λ} controller given by (2);

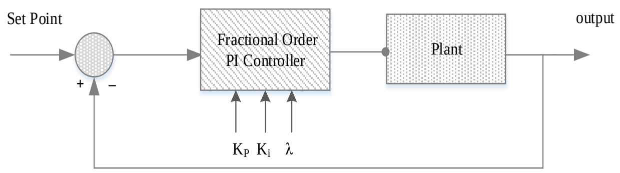

Fig. 2 Block-diagram of FOPI controller

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

III. Horizontal Cylindrical Tank System

The horizontal tank such as oil, chemical liquid in its surge drum level control system has shown Fig.3. The purpose of the surge vessel is to smooth variations in the flow from process one and maintain a relatively constant flow rate to process two. The level can vary substantially from the set point, as long as the vessel does not overflow or go dry. The main object is to vary the manipulated flow rate (the outlet flow from the vessel) as little as possible, while satisfying level constrains. Surge vessels are used to help reduce the effect of flow rate variations between interconnected process units. It is necessary to maintain tight level control in a surge vessel

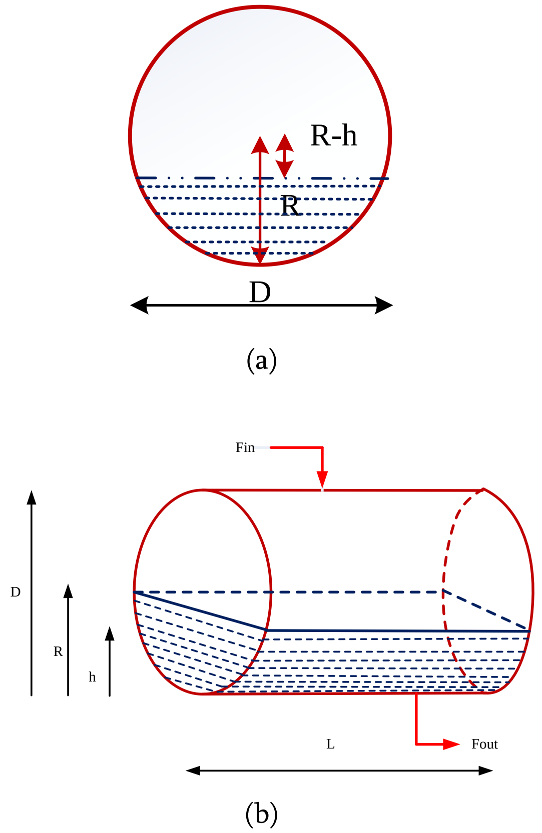

Fig. 3 The horizontal cylindrical tank model (a) Front view (b) horizontal view

The mathematical model of the horizontal cylindrical tank liquid level system considered for the study is expressed as

Let R, be radius of cross section.

h, be level of liquid inside the tank.

D, be diameter of cross section.

L, be height of the tank.

As per the conservation of mass,

$$\frac{dv}{dt} = F_{in} - F_{out} \tag{4}$$

Where dv/dt is change of volume of liquid in tank with respect to time

F_{in} - is Volume flow rate at inlet

F_{out} - is Volume flow rate at outlet

in conservation of mass,

$$2L\sqrt{Rh-h^2}\,\frac{dh}{dt} = F_{in} - F_{out} \quad (5)$$

$$\frac{dh}{dt} = \frac{F_{in} - F_{out}}{2L\sqrt{2Rh-h^2}} \quad (6)$$

Where

$F_{out} = c\sqrt{h}$, c is valve coefficient

$$\frac{dh}{dt} = \frac{F_{in} - c\sqrt{h}}{2L\sqrt{2Rh-h^2}}$$

This is the mathematical model of the horizontal cylindrical Therefore the equation holds good for all the different level of the tank.

IV. Craziness PSO Algorithm

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 [8-10].

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.

PSO uses particles which represent potential solutions of the problem. Each particles fly in search space at a certain velocity which can be adjusted in light of preceding flight experiences. The projected position of i^{th} particle of the swarm xi, and the velocity of this particle v_i at $(t + 1)^{th}$ iteration are defined and updated as the following two equations:

$$v_i^{t+1} = v_i^t + c_1 r_1 \left(p_i^t - x_i^t\right) + c_2 r_2 \left(g_i^t - x_i^t\right) \quad (7)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (8)$$

where i = 1, …., n and n is the size of the swarm, c1 and c2 are positive constants, r_1 and r_2 are random numbers which are uniformly distributed in [0, 1], t determines the iteration number (4), pi represents the best previous position (the position giving the best fitness value) of the i^{th} particle, and g represents the best particle among all the particles in the swarm. At the end of the iterations, the best position of the swarm will be the solution of the problem. It cannot be always possible to get an optimum result of the problem, but the obtained solution will be an optimal one. Fig. 4 shows the flowchart of craziness based PSO algorithm.

Since the standard PSO algorithm can fall into premature convergence especially for complex problems with many local optima and optimization parameters, the craziness based PSO algorithm which is particularly effective in finding out the global optimum in very complex search spaces is developed. The main difference between PSO and CRAZYPSO is the propagation mechanism to determine new velocity for a particle as follows:

$$v_i^{t+1} = r_2 \,\mathrm{sign}(r_3) v_i^t + (1-r_3) c_1 r_1 \left(p_i^t - x_i^t\right) + (1-r_2) c_2 (1-r_1)\left(g^t - x_i^t\right) \quad (9)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} + P(r_4)\,\mathrm{sign}(r_4) V_{cr} \quad (10)$$

Where

p_i is the local best position of particle i, and

g_i is the global best position of the whole swarm.

r_1, r_2, r_3 and r_4 are random parameters distributed uniformly in [0, 1], and

c_1, c_2 are named step constants and are taken 2.05 generally.

The sign is a function defined as follows for r_3 and r_4,

$$\mathrm{sign}(r_3) = \begin{cases} -1 \Leftarrow r_3 \le 0.05 \\ 1 \Leftarrow r_3 > 0.05 \end{cases}$$

$$\mathrm{sign}(r_4) = \begin{cases} -1 \Leftarrow r_4 \le 0.5 \\ 1 \Leftarrow r_4 > 0.5 \end{cases}$$

In birds flocking or fish schooling, since a bird or a fish often changes directions suddenly, in the position updating formula, a craziness factor, V_{cr} , is used to describing this behavior. In this study, it is decreased linearly from 10 to 1. $P(r_4)$ is defined as,

$$P(r_4) = \begin{cases} 1 \Leftarrow r_4 \le P_{cr} \\ 0 \Leftarrow r_4 > P_{cr} \end{cases}$$

Where P_{cr} is a predefined probability of craziness and is introduced to maintain the diversity of the particles. It is taken 0.3 in this project. The CRAZYPSO algorithm can prevent the swarm from being trapped in local minimum, which would cause a premature convergence and lead to fail in finding the global optimum [23].

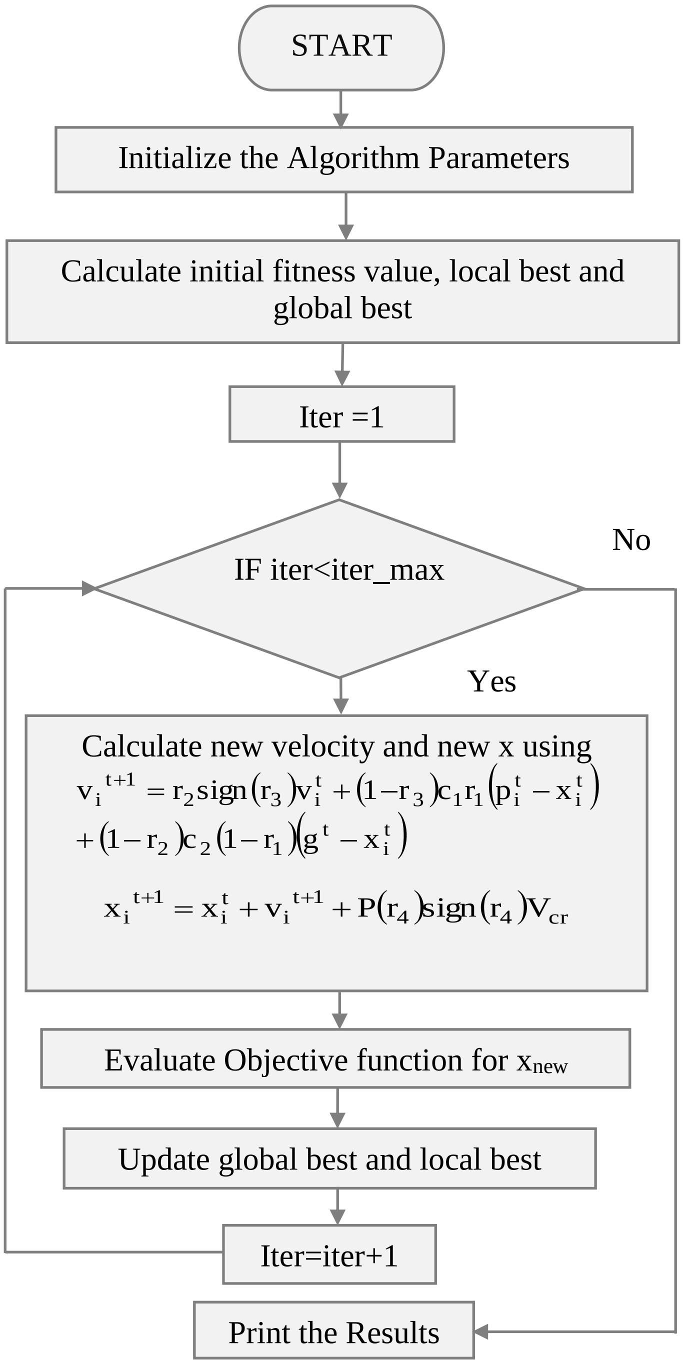

Fig. 4 Flowchart of Craziness based PSO algorithm

V. Simulation Results and Discussion

The analysis λ and μ values and applied to the Fractional Order PID Controller of the horizontal cylindrical tank system to verify the response of the controller. The stability of the system is verified with servo and regulatory responses using Crazy Particle swarm optimization (CPSO). Figs. 5-6 show the Simulink diagram of fractional order PI controller based Horizontal tank system. Figs.7, and

8 show the simulated responses of Horizontal cylindrical tank system using PI and FOPI controller parameters obtained using Conventional and CPSO method under Nominal case with set value of 30% in Level. Figs.9, 10 and 11 show the simulated responses of Horizontal Cylindrical tank system using PI and FOPI controller parameters obtained using Conventional and CPSO method with set point tracking at time period of t =10000 sec and t=15000 with value of 40 and 35. Figs.12,13 and 14 show the simulated responses of Horizontal Cylindrical tank system using PI and FOPI controller parameters obtained using Conventional and CPSO method with disturbances at time period of t =10000 sec and t=25000 with value of +5 and -5 respectively. The performance and analysis of Horizontal cylindrical tank process with PI and FOPI using conventional method and Crazy PSO algorithm shown in Table.1 It's clear that the Figs.9, 12 and 15 show the FOPI controller has better and quicker response than PI controller.

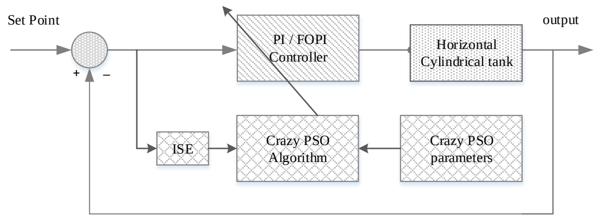

Fig. 5. Implementation of PID and FOPID controllers with horizontal cylindrical tank system using Crazy PSO

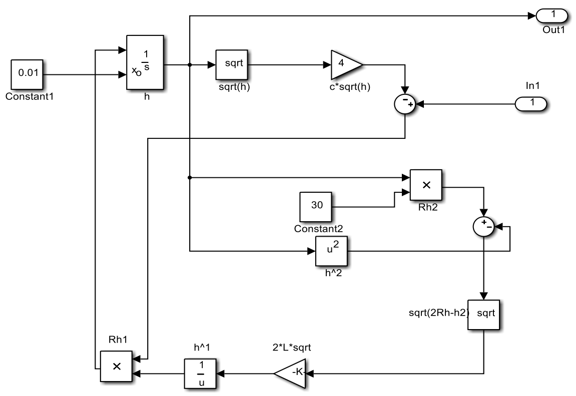

Fig. 6. Matlab Simulink model for Horizontal tank system

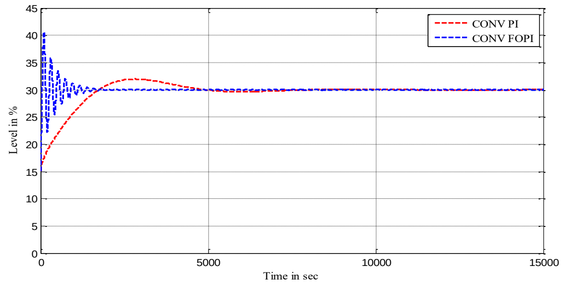

Fig. 7. Simulated response of HCT system using conventional PI and FOPI under nominal case

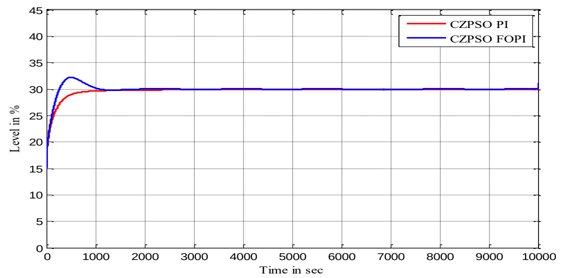

Fig.8. Simulated response of HCT system using Crazy PSO PI and FOPI under nominal case

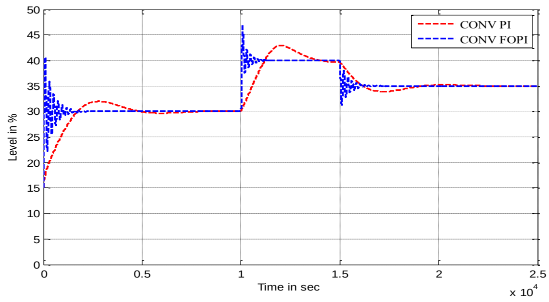

Fig. 9. Simulated response of HCT system using conventional PI and FOPI with set point tracking

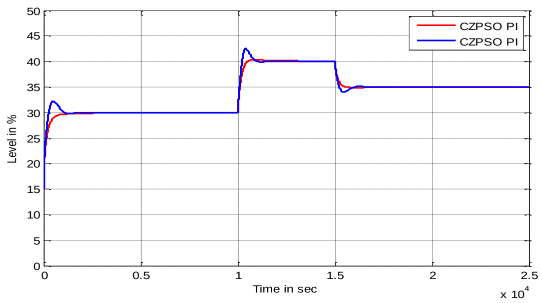

Fig. 10. Simulated response of HCT system using Crazy PSO PI and FOPI with set point tracking

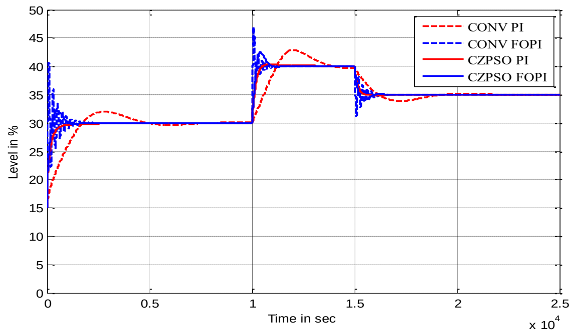

Fig. 11. Simulated response of HCT system using Conventional and Crazy PSO PI and FOPI with set point tracking

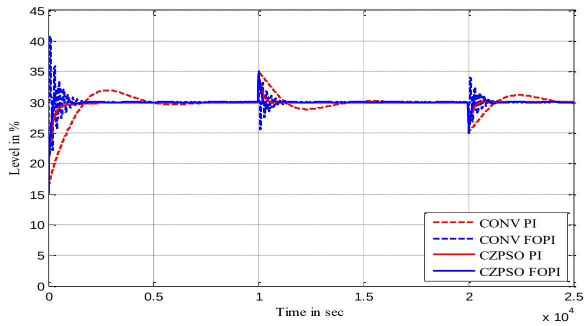

Fig. 12. Simulated response of HCT system using Conventional PSO PI and FOPI with disturbances

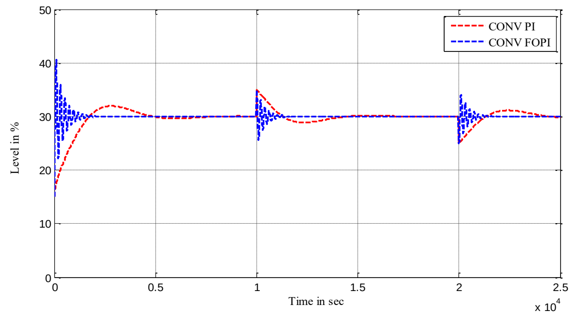

Fig. 13. Simulated response of HCT system using Crazy PSO PI and FOPI with disturbances

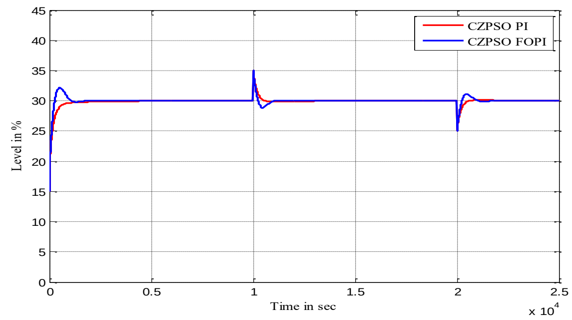

Fig. 14. Simulated response of HCT system using Conventional and Crazy PSO PI and FOPI with disturbances

Table.1 Performance and analysis of Horizontal cylindrical tank process with PI and FOPI using conventional method and Crazy PSO algorithm

Controller	Controller Parameters			Peak time sec	Max overshoot % mp	Settling time sec	Cost	
	K_P	K_i	λ				ISE	IAE
Conventional PI	1.4407	0.0023	-	2748	6.53	9886	6.5466e+10	1.016e+10
Conventional FOPI	0.7243	2.1850	0.9	99	36.4	2424	1.7029e+10	3.510e+9
CPSO PI	9.9831	0.00533	-	-	-	5124	3.8788e+09	8.1143e+8
CPSOFOPI	9.7975	0.0593	0.9150	497	7.6	1609	3.3395e+09	6.9436e+8

VI. CONCLUSION

The Crazy Particle swarm optimization (CPSO) tuned FOPI controller The λ and μ values and applied to the Fractional Order PID Controller of the horizontal cylindrical tank offers enhanced process characteristics such as better time domain specifications, smooth reference tracking, disturbance rejection, and error minimization compared with Conventional PI controller, FOPI and CPSO PI controller. The various results presented prove the performances of the CPSO tuned FOPI. The simulation responses for the models reflect the effectiveness of the CPSO based FOPI controller in terms of time domain specifications. The performance index under the various error criterions is always less than the CPSO tuned PI , FOPI and ZN PI controller.

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