ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 12, December 2013

Optimal Tuning of PI Controller using Swarm Intelligence for a Nonlinear Process

P.Aravind[1], Dr. S.M.GirirajKumar[2]

Assistant Professor, Department of Instrumentation and Control Engineering, Saranathan College of Engineering, Tamil Nadu, India[1]

Professor and Head, Department of Instrumentation and Control Engineering, Saranathan College of Engineering, Tamil Nadu, India[2]

ABSTRACT: This article deals with an application of Particle Swarm Optimization (PSO) to obtain a optimum PI controller settings for a non linear process. In this work, a conical tank level process is identified as first order plus dead time model (FOPTD). Control of level in conical tank is a complex issue but in the presence of gravity discharge flow conical tanks are used in industrial unit. PSO algorithm is used to tune the parameters of PI controller to control the level of the liquid in the conical tank. Efficacy of proposed method has been validated through a comparative study with gain scheduling method. The proposed method has excellent features of high computational efficiency. In this paper optimum values of PI controller settings are found and it is proved that the PSO based tuned PI values gives better results than the gain scheduling method. Hence the results demonstrates that the tuning of PI controller using PSO technique gives minimum rise time, minimum settling time than Gain Scheduling method and also reduces the IAE.

Keywords: PSO, Computation Intelligence, Gain Scheduling, PI Controller, Non Linear Process

I. INTRODUCTION

Role of PID controller in industries have been found more than fifty years [1]. Over the past 50 years research work on PID tuning methods are carried out which includes Ziegler-Nichols Ultimate-cycle tuning [1], Cohen-Coon's [2], Astrom and Hagglund [3] and many other techniques are also emerged. Since PID control has been an energetic research topic. PID controllers were widely used in many process plants; it gives satisfactory output from minimum plant information. These technique is highly appreciated by many researchers [6,8] because of the adjustments will be made in controller parameters with minimum attempt. PID controller must be properly tuned to get the desired response. Tuning a PID controller means setting the proportional, integral and derivative gain values to get the best possible control for a particular process.

In past few decades, to meet system demands researchers were deals with intelligent agents claiming that its a central ability of humans, intelligence [4, 5]. Owing the complexity in their real time implementation and tuning, the research community as well as the industrial to pay attention towards computation intelligence [9-11]. The computation efficiency is the advantage of particle swarm optimization algorithms over other tuning techniques.

Particle swarm optimization (PSO) is a computational algorithm technique based on swarm intelligence. This method is motivated by the observation of social interaction and animal behaviours such as fish schooling and bird flocking. It imitates the way they find food by the cooperation and competition among the entire population [7]. A swarm consists of individuals, called particles, each of which represents a different possible set of the unknown parameters to be optimized. The 'swarm' is initialized with a population of random solutions [9]. In a PSO system, particles fly around in a multi-dimensional search space adjusting its position according to its own experience and the experience of its neighbouring particle. The goal is to efficiently search the solution space by swarming the particles towards the best fitting solution encountered in previous iterations with the intention of encountering better solutions through the course of the process and eventually converging on a single minimum or maximum solution [10]. The performance of each particle is measured according to a pre-defined fitness function, which is related to the problem being solved.
The accuracy of the tuned controller is greatly dependent on the degree of accuracy of the system model. So the model of the process much more important. Analysis show that the design of proposed controller gives a better robustness, and, the performance is satisfactory over a wide range of process operations[12].Simulation results describes the

efficiency of the PSO based PI controller in point of improvement of performances in time domain specifications for a step response with that of gain scheduling algorithm.

The objective of the proposed work is to use Particle swarm optimization in order to obtain optimal values for PI controller parameters for a conical tank process. The dynamic behavior of a conical tank level system is high degree of non-linearity, and parameter is time variances in these processes make it extremely difficult to control. To overcome the problem of non linearity, the process must be linearized i.e. full range is sliced into linear regions. Hence we propose four set of PI parameters. Every possible controller setting represent a particle in the search space which changes its parameters proportionality constant, Kp, integral constant, Ki, in order to minimize the error function and in this case error function is taken as objective function. The error function used here is Integral of Absolute errors (IAE).In section 2, we have discussed in detail about the development of the mathematical model for the non-linear conical tank process. The tuning results of conventional techniques are discussed in section 3. Section 4 and 5 deal with the explanation of the PSO algorithm and its implementation. The comparative analysis and results are given in Section 6. The conclusions arrived, based on the results is given in Section 7.

II. MATHEMATICAL MODELING

The conical tank system shown in Figure1 is a system with nonlinear dynamics. Its nonlinearity is described by the differential equation [14].

It is derived according to law of conservation of mass,

Inflow rate - Outflow rate = Accumulation

$$\mathrm{Fin} - \mathrm{Fout} = \frac{d}{dt}[\mathrm{Total\ Volume} - \mathrm{Cap\ Volume}]$$

(1)

Total volume of the conical tank is $= \frac{1}{3}\pi r^2 H$

Cap Height = h_c

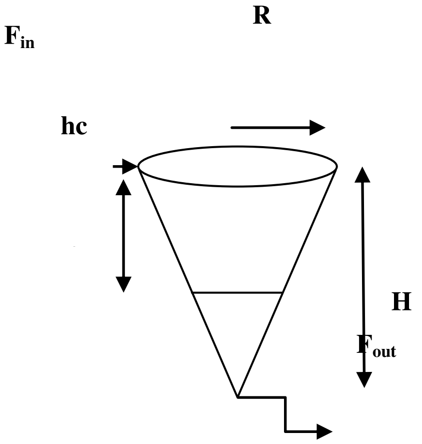


Figure.1 Schematic of Conical Tank

TABLE I
PROCESS OPERATING PARAMETERS

Sl no	Parameter	Description	Value
1	R	Top radius of the cone	19.25cm
2	H	Total height of the tank	73cm
3	F_{in}	Maximum Inflow rate	$111.11cm^3/s$
4	β	Valve Coefficient	$55cm^2/s$

By solving equation 1 we get,

$$\frac{dh}{dt} = \left(Fin - \beta\sqrt{h}\right) * \frac{1}{A} \qquad (2)$$

Where, $A = \frac{1}{3}\pi r^2 h$

The equation [2] describing the mathematical model for single conical tank level control, this equation is implemented in MATLAB Simulink. The basic method of identifying the system is step response method. A step change in inlet flow rate represents a process as first order transfer function with dead time.

$$G(s) = \frac{K_p e^{-\tau_d(s)}}{\tau s+1} \qquad (3)$$

Where K is the process gain; τ is the first order time constant; τ_d is the dead time (1 sec). Due to the non-linearity in the shape of the conical tank, a single range response cannot cover the entire range. So, full range of conical tank is sliced into different regions by introducing step change at various ranges, four responses were obtained for 0-1.44cm as model-1, 1.44-5.76cm as model-2, 5.76-12.83cm as model-3 and 12.83-23.04 cm as model-4 with process gain 0.0218, 0.0654, 0.109, 0.155 and time constant 0.041, 0.24, 1.97, 11.75 respectively.

III. ADAPTIVE CONTROL TECHNIQUE

In this paper a gain scheduling approach is discussed. It is a model based approach, PI controller parameter were identified from the model parameters. In this approach, gain is scheduled with respect to operating regions. This method has scheduling variable, based upon the scheduling variable PI controller gain values the proportional (K_p) and integral gain (T_i) are calculated [14,15].

$$K_p = \frac{\tau}{R}; T_i = \tau \qquad (4)$$

IV. PSO BASED PI CONTROLLER

A. *Particle Swarm Optimization*

In PSO algorithm, the system is initialized with a population of random solutions, which are called particles, and each potential solution is also assigned a randomized velocity. PSO relies on the exchange of information between particles of the population called swarm. Each particle adjusts its trajectory towards its best solution (fitness) that is achieved so far. This value is called p_{best}. Each particle also modifies its trajectory towards the best previous position attained by any member of its neighborhood. This value is called *gbest.* Each particle moves in the search space with an adaptive velocity.

The fitness function evaluates the performance of particles to determine whether the best fitting solution is achieved. During the run, the fitness of the best individual improves over time and typically tends to stagnate towards the end of the run. Ideally, the stagnation of the process coincides with the successful discovery of the global optimum.

Let *D* be the dimension of the search space taken into consideration and Xi = [xi1, xi2,….x_{iD}]^T denote the current position of ith particle of the swarm, Then: Xi pbest =[x_{i1}^{pbest},x_{i2}^{pbest},….x_{iD}^{pbest}]^T denote the best position ever visited by the particle.Xgbest =[x_{i1}^{gbest},x_{i2}^{gbest},….x_{i2}^{gbest}]^T represents 'gbest',i.e the best position obtained this far by any particle in the population. Vi=[v_{i1},v_{i2},….v_{iD}]^T represents the velocity of ith particle. Vimax = [v_{i1}^{max},v_{i2}^{max} ….v_{iD}^{max}]^T denotes the upper bound on the absolute value of the velocity with which the particle can move at each step.The position and velocity of the particles is adjusted as per the following equation:

$$Vid = w * v\,id + c1.* r1 * (x\,id\,pbest - x\,id) + c2 * r2 * (x\,gbest - x\,id) \quad (5)$$

$$V\,id = \begin{cases} vdmax, & v\,id > vdmax \\ -vdmax, & v\,id < -vdmax \end{cases} \quad (6)$$

$$xid = xid + vid \quad (7)$$

where c1 and c2 are positive constants, represent the cognitive and social parameter respectively; r1 and r2 are random numbers uniformly distributed in the range [0,1]; w is inertia weight to balance the global and local search ability. In general the PSO technique can be given by the following algorithm,

B. Algorithm

Step1: Start the program
Step2: Initialize particles with random place and velocity
Step3: Evaluate fitness value for each particle
Step4: If current fitness value is better than pbest, goto step5 else goto step8.
Step5: Pbest equal to current fitness value
Step6: If current fitness value is better than Gbest, goto to step7 else goto step 8
Step7: Gbest is equal to current fitness value.
Step8: Update position and velocity of particles
Step9: Goto step10 if stop criteria met else goto step3.

V. IMPLEMENTATION OF PSO ALGORITHM

The optimal values of the PI controller parameters Kp, Ki are found using PSO. All possible sets of controller parameter values are particles whose values are adjusted so as to minimize the objective function, which in this case, the error criterion is discussed in detail. For the PI controller design, it is ensured the controller settings estimated results in a stable closed loop system.

A. Selection of PSO parameters

To start up with GA, predefining certain parameters is necessary. It includes the population size, iteration length, velocity constants etc. Selection of these parameters decides to a great extent the ability of designed controller[13]. The size of swarm balances the requirement of global optimization and computational cost. Initializing the values of the parameters is listed in table II.

TABLE III
PSO SELECTION PARAMETERS

Parameters	Values
Population size	100
Number of iterations	100
Velocity constant,c1	2
Velocity constant,c2	2

A. Performance Index for the PSO Algorithm

The objective function considered is based on the error criterion. The performance of a controller is best evaluated in terms of error criterion. A number of such error criteria are available and in the proposed work, performance of the controller's is examined in terms of Integral of Absolute Errors (IAE) criterion, given in equation (8). The IAE weights the error with time and hence emphasizes the error values over arrange of 0 to T, where T is the expected settling time.

$$I_{IAE} = \int_0^T |e(t)|dt \qquad (8)$$

B. Termination criteria

Optimization algorithm will automatically terminate execution either when the number of iterations gets over or with the attainment of acceptable fitness value. Fitness value, in this case is nothing but reciprocal of the error, since we consider for a minimization of objective function. In this paper the termination criteria is considered to be the attainment of maximum number of iterations. The variation of the values (Kp,Ki) for four models during first iteration are sketched and shown in figure2- 9.

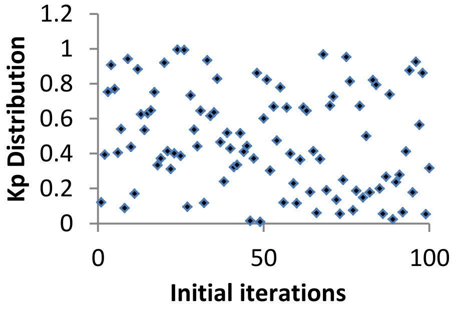


Figure.2. Distribution of Kp in first iteration for Model1

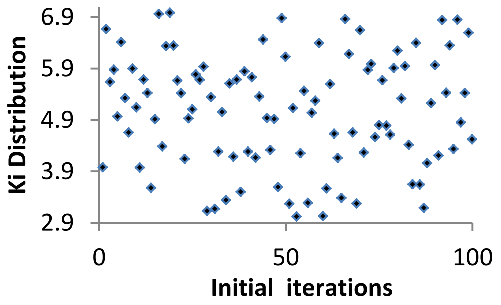


Figure.3 Distribution of Ki in first iteration for Model1

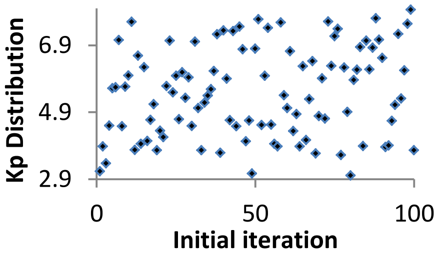


Figure.4. Distribution of Kp in first iteration for Model2

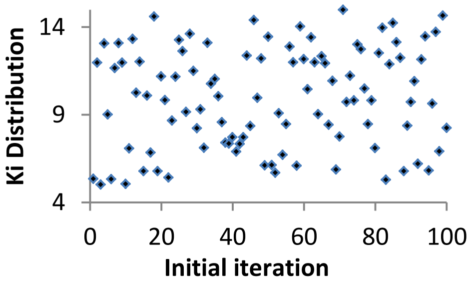


Figure.5 Distribution of Ki in first iteration for Model2

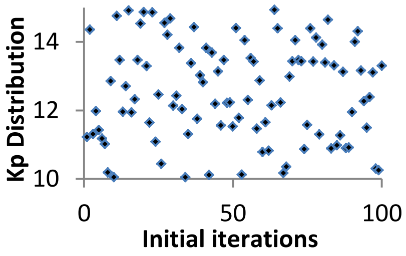


Figure.6. Distribution of Kp in first iteration for Model3

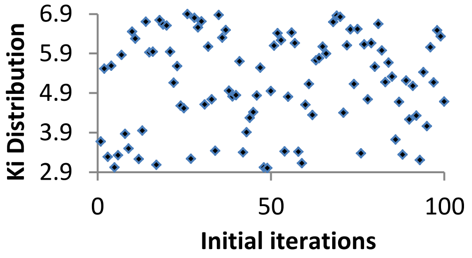


Figure.7 Distribution of Ki in first iteration for Model3

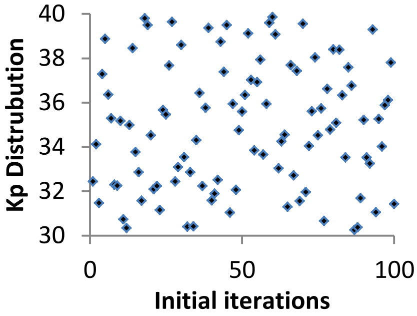


Figure.8. Distribution of Kp in first iteration for Model4

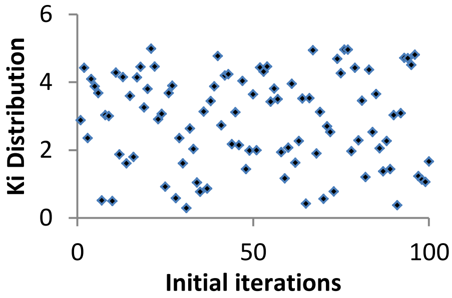


Figure.9 Distribution of Ki in first iteration for Model4

For each iteration the best among the 100 particles considered as potential solution is chosen. Therefore the best values for 100 iterations for four models are sketched and shown in figure10-13 with respect to iterations for Kp and Ki.

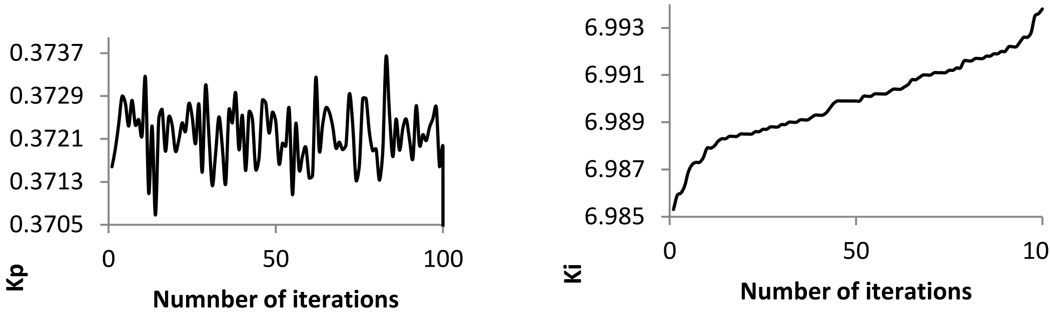


Figure.10 Best solutions of Kp , Ki for 100 iterations (Model 1)

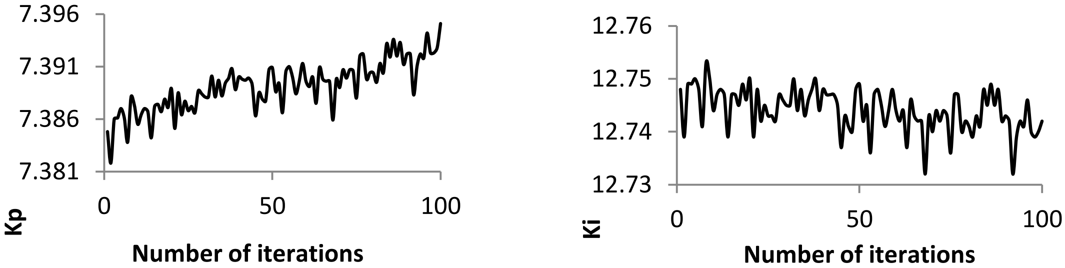


Figure.11 Best solutions of Kp , Ki for 100 iterations (Model 2)

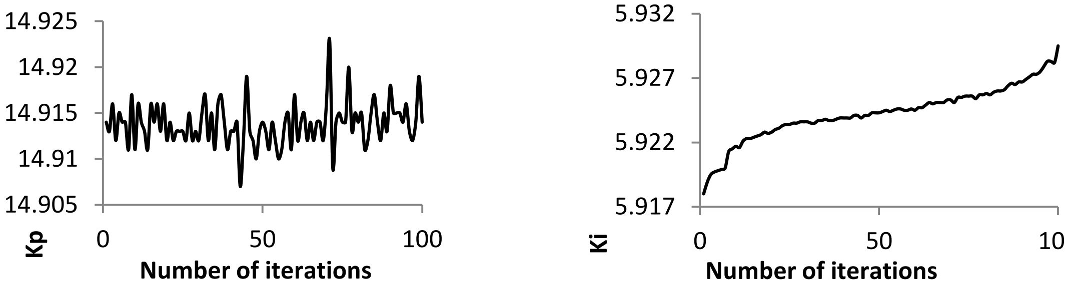


Figure.12 Best solutions of Kp , Ki for 100 iterations (Model 3)

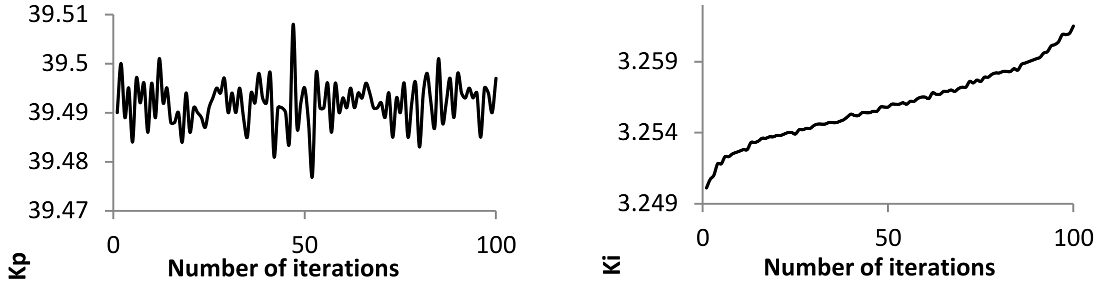
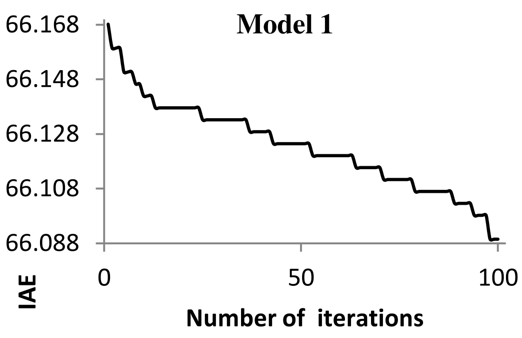


Figure.13 Best solutions of Kp , Ki for 100 iterations (Model 4)

The PI controller was formed based upon the respective parameters for 100 iterations, and the gbest (global best) solution was selected for the set of parameters, which had the minimum error. A sketch of the error based on IAE criterion for 100 iterations is given in figure.14 -17 for four models.



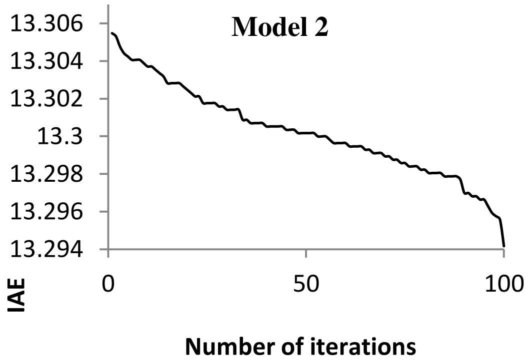
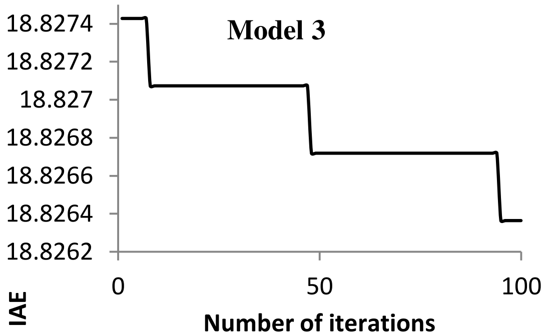


Figure.14 IAE response for 100 iterations

Figure.15 IAE response for 100 iterations



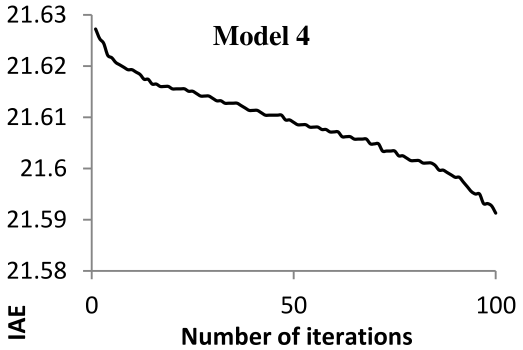


Figure.16 IAE response for 100 iterations

Figure.17 IAE response for 100 iterations

It was seen from figure 14-17 that the error value tends to decrease for a larger number of iterations. As such the algorithm was restricted to 100 iterations beyond which there was only a negligible improvement. Based on PSO algorithm for the application of the PI tuning, the tuned PI parameters were tabulated in table III.

TABLE III
TUNED GAIN VALUES OF CONTROLLER

Sl No	Model	GS		PSO	
		Kp	Ki	Kp	Ki
1	1	0.1509	0.9934	**0.37194**	**6.9938**
2	2	1.358	0.9069	**7.3951**	**12.742**
3	3	3.6379	0.5176	**14.914**	**5.9295**
4	4	7.586	0.5314	**39.497**	**3.2615**

VI. RESULT AND DISCUSSION

After the tuning process is done through adaptive method and proposed PSO technique, analysis was performed for step change; with the help of simulation environment application to the conical tank is examined. The time domain specifications comparison for the obtained models with the designed controller is presented in table IV. Four models was obtained as 0-1.44cm as model-1, 1.44-5.76cm as model-2, 5.76-12.83cm as model-3 and 12.83-23.04 cm .The four models are represented as first order transfer function with delay time.

The most important feature of the paper is presented in this section. The simulated responses of the conical tank of various set points with various PI controller settings are presented in the figures 18-21. The response of the process was observed by giving set point change at various time instant of 1.4cm, 5.7cm, 12.8cm and 23cm.

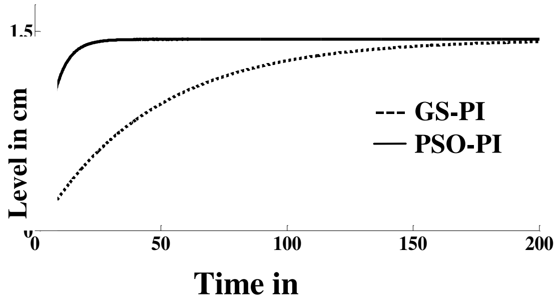


Figure. 18. Response for a setpoint of 1.4 cm

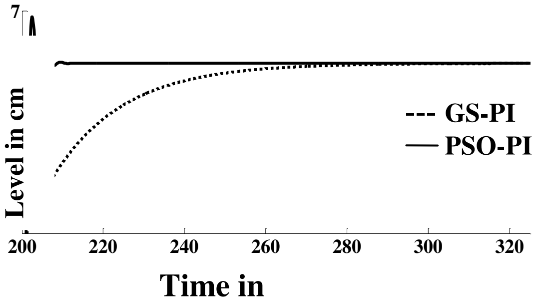


Figure. 19. Response for a setpoint of 5.7 cm

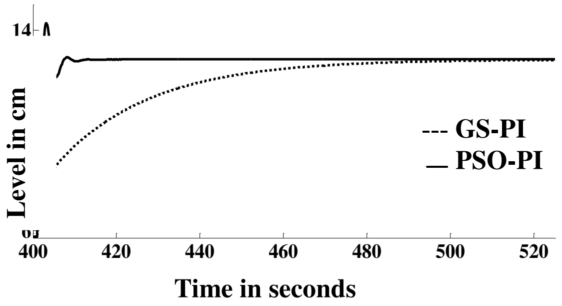


Figure 20 Response for a setpoint of 12.8 cm

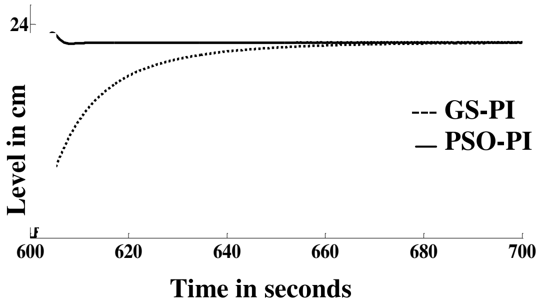


Figure. 21. Response for a setpoint of 23 cm

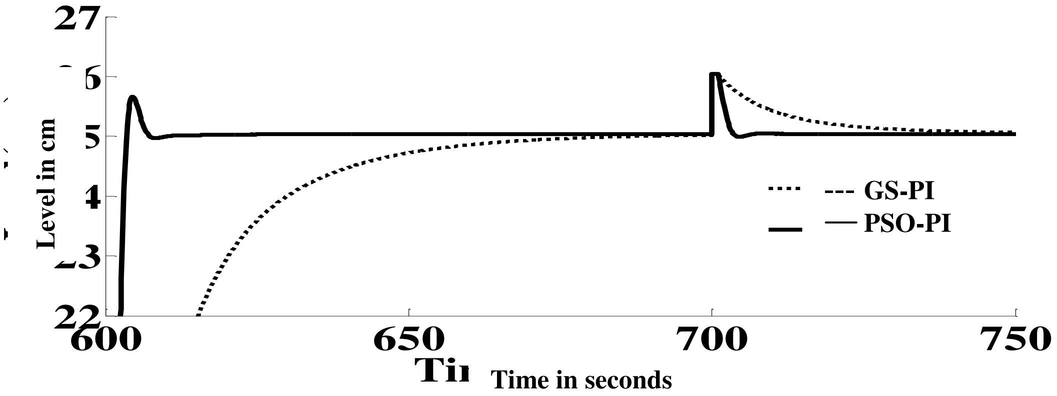


Figure 22 Response with disturbance in reference value 25 cm

Figure 22 clearly states that how fast the PSO based PI controller reacts to disturbance compare to GS based PI controller. A process is disturbed at the time of 700 seconds, the proposed PSO-PI controller reacts faster and process variable attains steady state in 6 seconds for setpoint 25cm.

TABLE IV
COMPARISON OF TIME DOMAIN SPECIFICATIONS

Setpoint (cm)	Performance	GS	GA
1.4	Peak time(secs)	-	-
	Rise Time (secs)	125	**40**
	Settling Time (secs)	125	**40**
5.7	Peak Time(secs)	-	**2.2**
	Rise Time (secs)	107	**1.8**
	Settling Time (secs)	107	**12**
12.8	Peak time(secs)	-	**3.2**
	Rise Time (secs)	148	**2.3**
	Settling Time (secs)	148	**13**
23	Peak time(secs)	-	**4.5**
	Rise Time (secs)	120	**3.5**
	Settling Time (secs)	120	**15**

VII. CONCLUSION

An analysis has been presented here that the tuned PI values based on PSO algorithm was tested in controlling of level in the conical tank. It comes out with a conclusion that the rise time(T_r) and settling time(T_s) is reduced drastically for PSO based tuned PI values compared to GS based tuned PI values. The simulation responses for the models are validated through time domain analysis and the effectiveness of the PSO based controller in time domain specification are tabulated in table IV.

The obtained results demonstrated that the PSO based PI controller yield good results than gain scheduling method. It is clearly represented in figure 22, a process is disturbed at time 700 seconds, the proposed PSO-PI controller responds quickly to disturbance and attains steady state within 6 seconds but GS based controller reaches steady state in 60 seconds at reference value of 25cm. The reaction rate of the proposed controller setting is 10 times faster than the GS based PI controller setting.

PSO presents multiple advantages to a designer by operating with a reduced number of design methods to establish the type of the controller, giving a possibility of configuring the dynamic behaviour of the control system with ease, starting the design with a reduced amount of information about the controller (type and allowable range of the parameters), but keeping sight of the behaviour of the control system. So this method of tuning can be applied to any system irrespective of its order and can be proved to be better than the existing traditional techniques of tuning the controller.

REFERENCES

[1] J. G. Ziegler and N. B. Nichols, "Optimum settings for automatic controllers," Trans. Amer. Soc. Mech. Eng., vol. 64, pp. 759–768, 1942.
[2] G.H Cohen and G.A Coon: Theoretical Consideration of Retarded Control , Trans ASME 75,pp.827/834,1953.
[3] Astrom, K J.;. Hagglund .T , Automatic tuning of simple regulators with specifications on phase and amplitude margins, Automatica, 20,645-651, 1984.
[4] Simon Fabri and Visakan Kadirkamanathan, Dynamic structure neural networks for stable adaptive control of nonlinear systems, IEEE Transactions on Neural Networks, Vol. 7, No. 5, 1996.
[5] Asriel U. Levin and Kumpati S. Narendra, Control of nonlinear dynamical systems using Neural Networks- Part II : observability, identification and control, IEEE Transactions on Neural Networks, Vol. 7, No. 1, 1996.
[6] Yonghong Tan Xuanju and Dang Achiel Van Cauwenberghe, "Generalised nonlinear PID controller based on neural networks", IEEE, Information decision and control,1999.
[7] Thomas Beielstein , K.E. Parsopoulos and Michael N. Vrahatis , "Tuning PSO Parameters Through Sensitivity Analysis, Technical Report of the Collaborative Research Center 531 Computational Intelligence CI--124/02, University of Dortmund, January 2002.
[8] S. Skogestad,. "Simple analytical rules for model reduction and PID controller tuning". J. Proc. Cont, Vol 13, pp .291 – 309, 2003.
[9] Y Zheng, Liyan Zhang, Jixin Qian Longhua Ma "Robust PID Controller Design using PSO" International Symposium on Intelligent Control IEEE, October 2003.
[10] T.Bartz–Beielstein K.E. Parsopoulos and M.N. Vrahatis, "Analysis of Particle Swarm Optimization Using Computational Statistics", International conference on numerical analysis and applied mathematics ICNAAM-2004.
[11] Jun Zhao, Tianpeng Li and Jixin Qian "Application of Particle Swarm Optimization Algorithm on Robust PID controller Tuning", Springerlink-Verlag Berlin Heidelberg , pp. 948-957, 2005.
[12] Xu, Z.-C, "Parameter tuning method of robust PID controller based on particle swarm optimization algorithm" Control and Instruments in Chemical Industry 33 (5), pp. 22-25, 2006.
[13] S. M. Giri raj Kumar, R. Sivasankar, T. K. Radhakrishnan, V. Dharmalingam and N. Anantharaman , "Particle Swarm Optimization Technique Based Design of Pi Controller for a Real-Time Non-Linear Process", Instrumentation Science & Technology, Volume 36, Issue 5, 2008 .
[14] V.R. Ravi., T. Thyagarajan , "Application of Adaptive Control Technique to Interacting Non Linear Systems, Electronics Computer Technology (ICECT)", 2011 3rd International Conference, 386 – 392, 2011.
[15] P.Aravind, M.Valluvan2, S.Ranganathan,"Modelling and Simulation of Non linear Tank", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 2, Issue 2, February 2013.
[16] P Aravind, M Valluvan , M Saranya ," Simulation based Modeling and Implementation of Adaptive Control Technique for Non Linear Process Tank, International Journal of Computer Applications (0975 – 8887) Volume 68– No.16, 2013.
[17] D. Mercy, S.M.Girirajkumar, "Tuning of Controllers for Non Linear Process using Intelligent Techniques", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 2, Issue 9, September 2013.