Controlling of Temperature Process using IMC-PID and PSO

N.Nithyarani1
Assistant professor
Dept of Instrumentation & Control
Saranathan College of Engineering, Trichy, India

S.M.GirirajKumar
Professor & Head
Dept of Instrumentation & Control
Saranathan College of Engineering, Trichy, India

K.Mohamed Hussain
UG Student
Dept of Instrumentation & Control
Saranathan College of Engineering,Trichy, India

Abstract

In plant process control industries, automatic controllers are introduced. Proportional-Integral- Derivative (PID) controllers are the workhorses of many industrial controller requests. The frequently used Ziegler Nichols, most popularly called as ZN, tuning method holds good for a system with small decay ratio and fails when decay ratio is large and tuning is also difficult. Internal Model Controllertuning rules enhance the control performance by determining one tuning parameter, the filter time constant. The need for improved performance of the process has led to the development of robust and optimal controllers. In this paper, the objective ofthe controller design is to maintain the temperature of water in the liquid tank in a desired value. System identification of this temperature process is done by empirical method, which is notorious to be nonlinear and approximated to be a (First Order Plus Dead Time) FOPDT model. The advanced control system, IMC-PID and Particle Swarm Optimization (PSO) is designed for this FOPDT process model. PSO algorithm is implemented and the performance is compared with the conventional PID and IMC algorithm in terms of performances indices. It is observed that PSO for the system provides optimum values of performance indices.

Keywords: PID ZN-II, IMC, IMC-PID,PSO, System Identification

I. INTRODUCTION

The Proportional-Integral-Derivative (PID) algorithm was invented in the 1940's and remains substantial useful and applicable over a large range of process challenges. PID controllers are used to control the process variables ranging from pressure, fluid flow, temperature,density consistency, etc. It is a robust easily understood algorithm that can provide outstanding control performance despite the varied dynamic characteristics of process plant. PID is also the root for many advanced control algorithms and strategies. In order for control loops to work appropriately, the PID loop must be accurately tuned. Designing and tuning a PID controller demands flexible algorithms, if multiple and incompatible objectives are to be achieved. A conventionally tuned PID controller with fixed parameters may usually derive lesser control performance when it comes to system demands. The conventional tuning techniques lack the intelligence and flexibility which would increase the performance rate and also improvise the stability and error criterion.

Particle swarm optimization (PSO) is a computational algorithm technique based on swarm intelligence. This method is driven by the statement of collective interaction and animal activities such as bird flocking and fish schooling. It simulates the way they find food by the cooperation and competition among the entire population [12]. A swarm contains of individuals called particles, each of which characterizes a different possible set of the unknown parameters to be optimized. The 'swarm' is initialized with a population of random solutions [10]. 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 neighboring 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 [9]. The performance of each particle is measured according to a pre-defined fitness function which is related to the problem being solved. The use of PSO has been reported in many of the recent works [8] PSO has been regarded a promising optimization algorithm due to its low computational cost, simplicity and good performance [7].

The model of the process under study is very important for its tuning as the accuracy of the tuned controller parameters is greatly dependent on the degree of accuracy of the system model with that of the real system. As per the fundamentals it is possible to approximate the actual input-output mathematical model of a very-high-order, complex dynamic process with a simple model consisting of a first or second order process combined with a dead-time element [6]. Thus a common practice followed in industries for the purpose of control design and process analysis is to model the dynamics of the processes near the operating point by simpler models such as FOPTD [5].

Analysis show that the design of anticipated controller gives aimproved robustness and the performance is satisfactory over a wide range of process operations[4].Simulation results illustrate the efficiency of the proposed controller in point of improvement of performances in time domain specifications for a step response. The controller designed is self-determining of the mathematic model of networks, thus getting free of the adverse effects [3,2].Hence, in industries the difficulties to achieve an optimal PIDgain without prior expert knowledge, can be overcome. By using the PSOmethod, global and local results could be instantaneously found for better tuning of the controllerparameters[1].

The objective of the paper is to use the PSO algorithm in order to obtain optimal PID controller settings for a Heating tank process, which is non-linear in nature. We hence propose for three set of PID parameters. Each possible controller setting characterize a particle in the search space which changes its parameters proportionality constant Kp, integral constant Ki and derivative constant Kd, in order to minimize the error function (objective function in this case). The error function used here is Integral Time of Absolute errors (IAE).In section 2, we have discussed in detail about the development of the mathematical model for the non-linear Heating tank process. The controllers tuning results of conventional techniques are discussed in section 4. Section 5 deal with the explanation of the PSO algorithm and its implementation. The comparative results are given in Section 6. The conclusions arrived based on the results is given in Section 7.

II. TEMPERATURE PROCESS

The aim of the paper is to control or to uphold the temperature of a liquid tank in a desired limit. The controller can be used to control the temperature of any plant or process. Normally it contains a Temperature input unit, Controller and Control output unit [3]. The ADC (Analogto-Digital) unit in concert with temperature sensor, that forms the temperature input unit and the SSR (solid state relay) driver forms the control output unit. Electric power to the heating element (heater) is supplied through relay contacts[3]. The switching of the relay, supply the heat to the tank. Here the process is a liquid tank with a heating element(heater) and with two temperature thermocouple sensors[18]. The basic block diagram and the experimental setup of the process is given in the following figures.

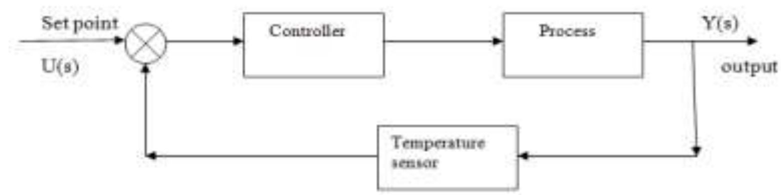

Fig. 1 Block diagram of a temperature process

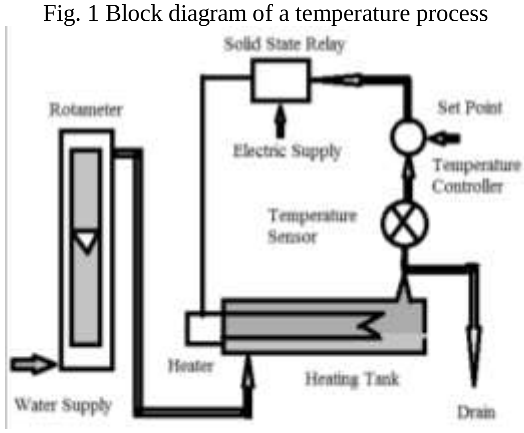

Fig.2: Experimental setup for temperature process

The process model on which the simulator is based is a First- Order model based on energy balance under the assumption of homogenous conditions of the liquid in the tank. The system also contains a time delay which represents the time delay which in practice exists betweenthe response in the temperature sensor and an excitation of the heating element. In addition to that simulator contains a first order transfer function representing a time constant in the heating element. A temperature process system for a water tank with continuous inflow and outflow is simulated. The water is heated by a heater which is controlled by the controller. The process variable is measured by a temperature sensor whichis thermocouple sensor[3].

III. SYSTEM IDENTIFICATION

The experimental determination of the dynamic behaviour of the process is called SI (system identification). System identification can be done mainly in two ways one is the mathematical modelling and the other is the empirical modelling. The mathematical modelling equations relating the input and the output are formed. Empirical methods use data gathered from experimental setup to define the mathematical model of a system. In this paper, empirical method is used for the temperature process. The transfer function for the process model is obtained from step response. The liquid tank temperature control system measured here can be assumed as a (FOPDT) first order process with dead time [3]. So for a first order process with dead time the parameters that are to be determined are the process gain (K), Delay time (td) and the time constant (τ).

Most often it has units of minutes or seconds. Step test data implies that the process is in manual mode (open loop) and initially at steady state. The transfer function of the process models are required only for the simulation studies of the controller design. Here, we are controlling the outlet temperature of the liquid tank[18][19]. The most commonly used model to describe the dynamics of the industrial temperature process is general First Order plus Time Delay Process (FOPTD).
And the FOPTD model structure is given in equation

$$G(s) = \frac{K}{(\tau s+1)}e\text{-}tds$$

Where, td – Time delay, K – Process gain, τ - Time constant.

Time delay between an excitation in the heating element and the response in the temperature sensor. Here the process of interest is approximated by a First Order plus Time Delay Process. The dead time approximation can be done in several methods; one of the methods are discussed below:

The pade approximation:

$$\text{Pade} = \frac{\left(-\frac{td}{2}\right)S+1}{\left(\frac{td}{2}\right)S+1}$$

$$\text{Pade} = \frac{-0.5s+1}{0.5s+1}$$

Thus by approximating the time delay using above mentioned approaches, we can determine that a (FOPTD) First Order PlusTime Delay Process can be approximated as a higher order process. The transfer function parameters of the process are obtained by doing the step test. The transfer function parameter for the temperature process is experimentally obtained as 7/(12s+1) * e-tds.

IV. CONTROLLER DESIGN

The basic PID controller parameters are given as, proportional gain Kp, integral gain Ki and derivative gain Kd Over the last fifty years, many methods have been industrial for setting the parameters of a PID controller. Inthis paper it is measured to proceed with Internal ModelControl (IMC) tuning technique proposed by Skogestad for PID tuning [1]. IMC involves a dissimilar structure and controller, a single IMC can be used for multivariable systems and it has zero steady-state offset for step-like inputs[2].

A. Internal Model Controller

Internal Model Controller involve a model based procedure,where the process model is implanted in the controller. IMC involve a single tuning parameter the filter constant. Here we consider a linear transfer function model of the temperature process[1]. Figure 3 shows the general block diagram of the IMC controller structure.

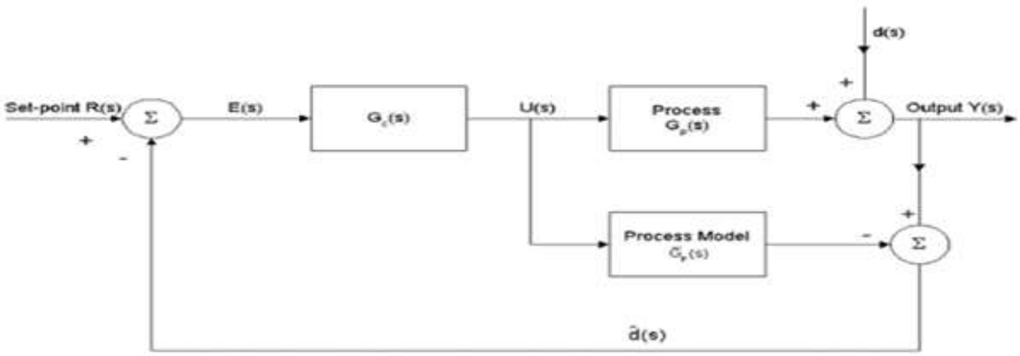

Fig. 3 Schematic of IMC

A controller $G_c(s)$ is used to control the process $G_p(s)$. Suppose p(s) is a model of $G_p(s)$. By setting $G_c(s)$ to be inverse of the model of the process, $G_c(s) = \bar{G}_p(s) – 1$ and if $G_p(s) = \bar{G}_p(s)$, (the model is an exact representation of the process) The process output is closely equal to the set point (SP)or to the reference input. The ultimate act of the controller is attainwithout any feedback requires [2]. From this closed loop expression, $G_c(s) = \bar{G}_p(s) – 1$, and if $G_p(s) = \bar{G}_p(s)$, then perfect set point tracking and disturbance rejection is achieved. If $G_p(s) \neq \bar{G}_p(s)$, perfect disturbance rejection can still be realized provided $G_c(s) =\bar{G}_p(s) – 1$.[18][19]
To get better robustness of the controller, the effects of process model difference should be minimized. This mismatch usually occur at the high frequency range and at the end of the system frequency response, Gf(s) a low-passfilter is usually added to attenuates the effects of processmodel difference[7]. Thus the IMC is usually designed as the inverse of the process model in series with a low-pass filter, that is GIMC (s) = Gc (s) Gf (s).

The most common used industrial controller is still the Proportional Integral and Derivative controller. It gives a transparent framework for a control system designs and tuning. Here IMC PID is implemented in this paper. It is an advanced control technique [2]. By using this controller technique it will gives the faultless control and stable results. IMC is a two degree controller. IMC gives

both the set point (SP)tracking and external disturbance rejection. The purpose of the IMCPID controller is achieved by the IMC block diagram rearrangement to the form of a standard feedback closed loop system. In IMC strategy, for a number of ordinary process transfer functions, it is equivalent to PID feedback controllers [7]. This use an approximation for time delays in order to find a PID-Type control law. Thus GPID (s) = GIMC (s) / 1- GIMC (s) $\bar{G}$p(s)
GPID (s) = $\bar{G}$p +(s)-1 Gf (s) / 1- $\bar{G}$p– (s) Gf (s)

For the (FOPTD) first-order plus time-delay process it is given by

$$\bar{G}p(s) = \frac{K\exp(-tds)}{1+\tau s}$$

This is the temperature process model with first-order plus time-delay. Applying the technique we get the IMC tuning parameters as Kp= 0.2025, Ki = 1.5, Kd= 0.3 for the proposed model.

V. PSO BASED PID 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 allocated a randomized velocity. PSO depend on the exchange of data between particles of the population called swarm. Every particle adjusts the situation trajectory towards its best solution (fitness) that is achieved so far. This value is called p_{best}. Every 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:

$V_{id} = w*v_{id} + c1.*r1 * (x_{id}^{pbest} - x_{id}) + c2 *r2 *(x^{gbest} - x_{id})$.

$V_{id} = \begin{cases} v_d^{max}, & v_{id} > v_d^{max} \\ -v_d^{max}, & v_{id} < -v_d^{max} \end{cases}$

$x_{id} = x_{id} + v_{id}$

wherec1 and c2 are positive constants, represent the cognitive and social parameter correspondingly; 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 algorithm can be given by the following flowchart, in figure.4.

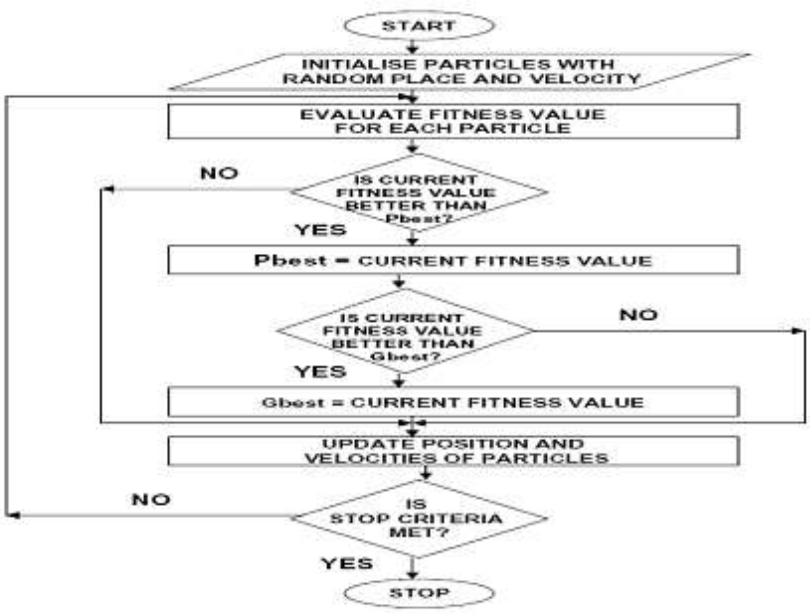

Fig.4 PSO Algorithm flowchart

B. Implementation of PSO Algorithm

The optimal values of the conventional PID controller parameters Kp and Ki, is found using PSO. All possible sets of controller parameter values are particles whose values are attuned so as to minimize the objective function, here in this case is the error criterion. For the PID controller design, it is ensured the controller settings predictable results in a stable closed loop system.

C.Selection of PSO parameters:
To start up with PSO, certain parameters arerequirement. Choice of these parameters selects to a great extent the ability of global minimization. The maximum velocity affects the ability of escaping from local optimization and refining global optimization. The size of swarm balances the requirement of global optimization and computational cost. Initializing the values of the parameters is as per table.1.

Table.1.PSO selection parameters

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

D. Performance Index for the PSO Algorithm
The objective function considered is based on the error performance criterion. The performance of a controller is best evaluated in terms of error criterion. A number of such criteria are available and in the proposed work, controller's performance is evaluated in terms of Integral of Absolute Errors (IAE) criterion, given by

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

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.

E. Termination Criteria
Termination of optimization algorithm can take place either when the maximum number of iterations gets over or with the attainment of satisfactory fitness value. Fitness value is nothing but reciprocal of the error, since we consider for a minimization of objective function. In this work the termination criteria is considered to be the maximum number of iterations. The variation of the values for the first iteration for Kp, Ki and Kd are given below for model as shown in Figure 5, 6 & 7. It is clearly seen that the values are well distributed.

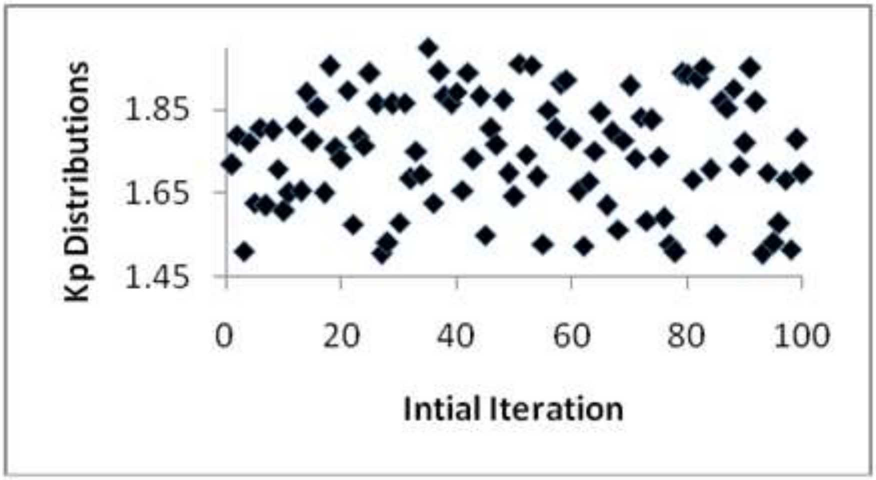

Fig.5 Distribution of Kp in first iteration

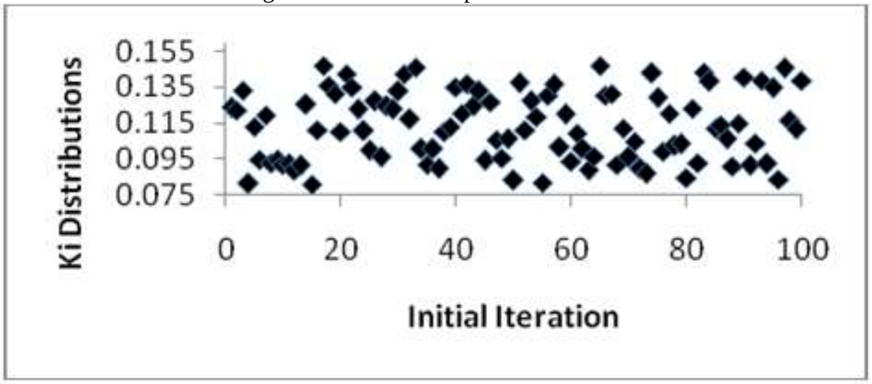

Fig.6 Distribution of Ki in first iteration

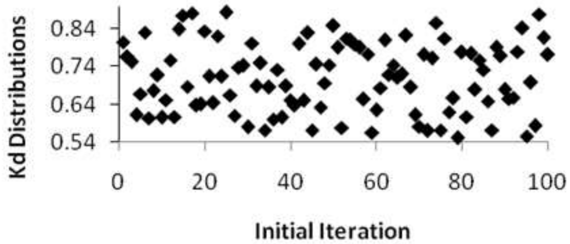

Fig.7 Distribution of Kd in first iteration

For each iteration the best among the 100 particles considered as potential solution is chosen. Therefore the best values for 100 iterations are sketched with respect to iterations for Kp and Ki and Kd and are shown in the following figures.

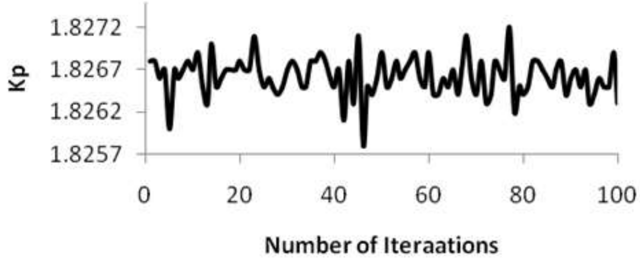

Fig.8: Best solutions of Kp for 100 iterations

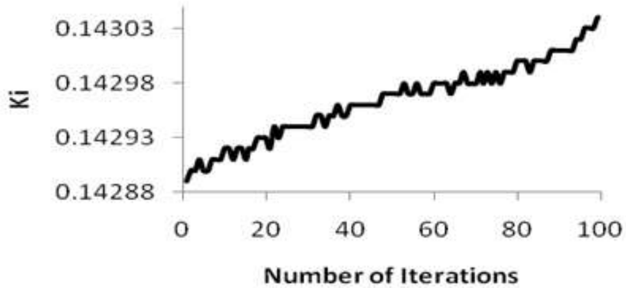

Fig.9: Best solutions of Ki for 100 iterations

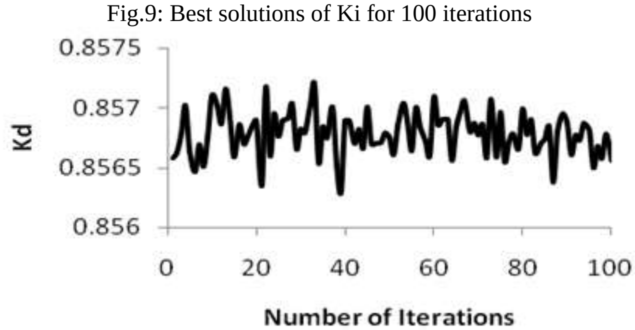

Fig.10 : Best solutions of Kd for 100 iterations

The PID 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 criterion. A plot of the error based on IAE criterion for 100 iterations is given in figure 11.

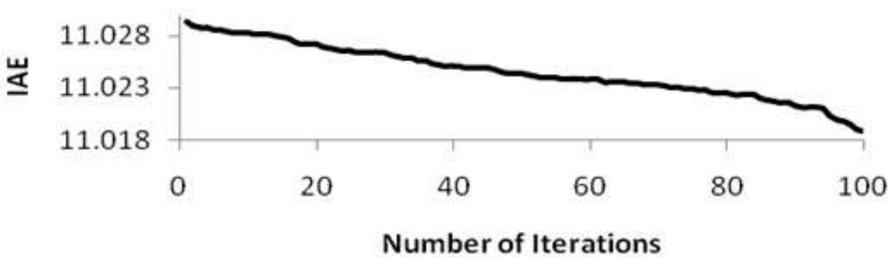

Fig.11: IAE values for 100 iterations

VI. Results and Comparison

The tuned values through the traditional as well as the proposed techniques are analyzed for their responses to a unit step input, with the help of simulation and then the real time application for the liquid heating tank is presented. A tabulation of the time domain specifications comparison and the performance index comparison for the obtained models with the designed controllers is presented.

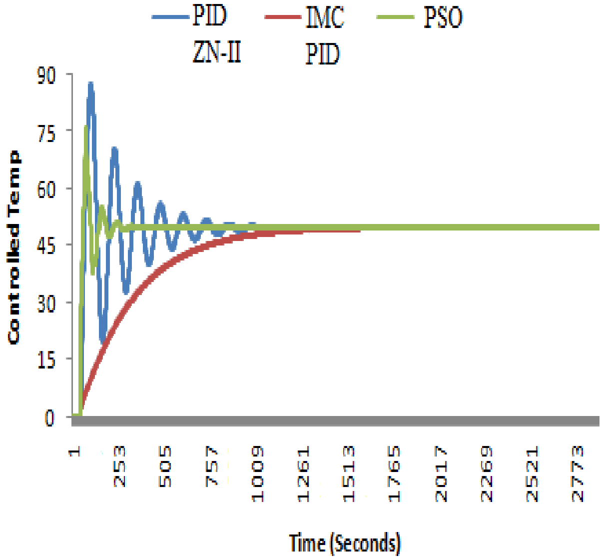

Fig.12 Simulated result for the temperature process

It is clear from the responses that the PSO based controller has the advantage of a better closed loop time constant, which enables the controller to act faster with a minimum overshoot and settling time. The response of IMC-PID controller is more sluggish than the PSO based controller. The time domain specification comparison is done for the IMC-PID and PSO based controllers for the responses obtained, is tabulated and given in table.3

Table.3. Time domain specification comparison

	PID ZN-II	IMC-PID controller	PSO controller
Rise time (seconds)	70	30	10
Peak time (seconds)	150	-	35
Overshoot	40	-	15
Settling time (seconds)	1261	1009	350
IAE	188.23	100.35	11.02

VII. Conclusion

The developed controller tuning for various set points can be suitably tracked by providing a program which can allow the system to choose that value based on the set point selected.The various results presented prove the betterness of the PSO tuned PID settings than the IMC-PID tuned ones. The simulation responses for the models validated reflect the effectiveness of the PSO based controller in terms of time domain specifications. The performance index under the various error criterions for the proposed controller is always less than the IMC-PID tuned controller. Above all the real time responses confirms the validity of the proposed PSO based tuning for the liquid heating tank system. PSO presents multiple advantages to a designer by operating with a reduced number of design methods to establish the type of the controllers, giving a possibilities of configuring the dynamic performanceof the control system with ease and starting the design with a reduced amount of information about the controller, but keeping sight of the performance of the control system. These features are illustrated in this work by considering the problem of designing a control system for a plant of first-order system with time delay and deriving the possible results. The future scope of the work is aimed at providing an on-line self tuning PID controller with the proposed algorithm so as solve complex issues for real time problems.

References

[1] J.A.Arulandu, Braatz and Horn, I.G., C.J.Gombas, J.G.VanAntwerpand R.D.Braatz, “Improved Filter Design in Internal Model Control” Imd.Eng.Chem., 35 (10), 3437-3441.

[2] Chein, I.L. and P.S.Fruehauf, “IMC-Based PID controllers for “Real PID Control” Consider IMC Tuning to Improve Controller Performance” Chem.Eng.Prog.86(10), 33-41.

[3] European Journal of Scientific Research, Euro Journals Publishing, ISSN 1450-216X Vol.78 No.1. pp.65-73. 2012.
[4] DanlelE.Rlvera, Manfred Morarl, and SlgurdSkogestad Chemical Engineering, "Internal Model Control" 206-41.
[5] PID Controller Design" California Institute of Technology, Pasadena, California 9 1 125.
[6] M.Shamusuzzohal and Moonyong Lee "IMC Filter Design for PID Controller Tuning of Time Delayed Processes".
[7] B.WayneBequette "Process Control Modeling, Design, and Simulation" by Prentice-Hall, Inc. 2003.
[8] E.Zafiriou, and Morari, M., Robust "A complete IMC design procedure Process Control, Prentice-Hall, Upper Saddle River, NJ.
[9] R. Oonsivilai and A. Oonsivilai,„PSOs Turbine Optimal PID Tuning by Genetic Algorithm using MSE" World Academy of Science, Engineering and Technology.
[10] K.S. Tang, K.F. Man, S. Kwongand Q.HE "Genetic Algorithm and their Apllications"
[11] Pintu Chandra Shill, Md. Faijul Amin, M. A. H. Akhand, and Kazuyuki Murase Optimization of Interval Type-2 Fuzzy Logic Controller Using Quantum Genetic Algorithms WCCI 2012 IEEE World Congress on Computational Intelligence June, 10-15, 2012
[12] Sameh F. Desouky Howard M. Schwartz A Novel Technique to Design a Fuzzy Logic Controller Using Q learning and Genetic Algorithms in The Pursuit-Evasion game IEEE International Conference on Systems, Man, and Cybernetics San Antonio, TX, USA - October 2009
[13] S. Nithya, Abhay Singh Gour, N. Sivakumaran, T. K. Radhakrishnanand N. Anantharaman, Model Based Controller Design for Shell and Tube Heat Exchanger, Sensors and Transducers Journal, Vol. 84, Issue 10, pp. 1677-1686, October 2007.
[14] D. Rathikarani, D. Sivakumar and S. Anita Janet Mary, Genetic algorithm based optimization of controller tuning for processes with dead time, Proceedings of the International conference on Advances in control and optimization of dynamical systems(ACDOS), 2007.
[15] PSOng-Wook Shin, Young-Joo Song, Tae-Bong Lee and Hong-KyooChoi, Genetic algorithm for identification of time delay systems from step responses, International Journal of Control, Automation, and Systems, Vol. 5, No. 1, Feb 2007, pp. 79-85.
[16] M. V. Sadasivarao and M. Chidambaram, PID controller tuning of cascade control systems using genetic algorithm, Journal of Indian Institute of Science, 86, July-Aug 2006, pp. 343-354.
[17] N.Nithyarani, S.M.Girirajkumar and Dr.N.Anatharaman, Modeling and Control of Temperature Process using Genetic Algorithm, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. Vol.2, Issue 11, November 2013.
[18] N.Nithyarani and S.Ranganathan, Advances in Control Techniques and Process Analysis with LabVIEW and DCS, International Journal of Electronics, Communication & Instrumentation Engineering Research and Development. Vol.3, Issue 2, Jun 2013.
[19] N.Nithyarani. Advanced process Analysis on LabVIEW, International Journal of Advanced Research in Electrical and Electronics Engineering. Vol.1, No.1 Nov 2013.