Particle Swarm Optimization Technique for Temperature Process

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Abstract — The increasing complexity of the modern control systems has emphasized the idea of applying new approaches in order to solve design problems for different control engineering applications. Proportional-Integral-Derivative (PID) control schemes have been widely used in most of process control systems represented by chemical process for a long time. However, it is still a very key problem on how to determine or to tune the PID parameters, because these parameters have a great manipulate on the stability and the performance of the control system. In this paper, we discusses in detail about the Particle swarm Optimization (PSO) is an optimization method that belong to the swarm intelligence unit and its implementation in PID tuning for a controller of a Temperature Process. Compared to other conventional PID tuning methods like PID-ZN II, IMC-PID the result shows that improved performances are achieved with the proposed one. The ability of the PSO designed controller in terms of servo operation is also compared with conventional techniques and the results are simulated by using MATLAB.

I. INTRODUCTION

In any of the Process Control and Process Automation Control Industries, controller designing is the most central part. The objective of this paper presents the analysis of temperature process and robust controller. Control or maintaining the temperature at a desired state is an important and common task in all process industries [1]. The PID algorithm was invented in the 1940's, and remains significant useful and relevant over a large range of process challenges [2]. They provide the best solutions for most problems. The conventional methods of PID tuning are rigid and often cumbersome. Although various other intelligent techniques have been used in past few years to meet the industrial requirements, there utility and incorporation is limited due to the inherent complexities arising at the time of implementation. Model based control and an internal model based PID controller is developed to control the temperature of the system [3]. IMC is a practical control design strategy that is employed in many advanced control plan packages. IMC is better than the PID controller [4]. For the optimal operation and real time application, an accurate explanation of the time domain system fast and robust controller is required.

Optimization algorithms are another area that has been receiving increased attention in the past few years by the research community as well as the industry. An optimization algorithm is a numerical method or algorithm for finding the maxima or the minima of a function operating with certain constraints [5]. Particle swarm optimization (PSO) is a computational algorithm technique based on swarm intelligence unit. A swarm consists of individuals called particles, each of which represents a different possible set of the unknown parameters to be optimized [6]. The 'swarm' is initialized with a population of random solutions. In a PSO particles fly about in a multi-dimensional search space adjusting its position according to its own experience and the experience of its neighboring particle [7]. 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[8].

The objective of the paper is to use the PSO algorithm in order to obtain optimal PID controller settings for a temperature process, which is non-linear in nature. The problem of non-linearity is overcome by linearizing. We hence propose for three set of PID parameters. Every possible controller setting represent 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. The error function used here is Integral Absolute Error (IAE). In section 2, we have discussed in detail about the mathematical model for the temperature process. The tuning results of PID controller conventional techniques are discussed in Section 3. Section 4 deals with the enlightenment of the PSO algorithm and Section 5 deals with the PSO technique implementation. The comparative studies of the different controllers tuning and its results are given in Section 6. The conclusion is given in Section 7.

II. TEMPERATURE PROCESS

The objective of this paper is to maintain and to control the outlet tempeature of the heating liquid tank within a specific derired range[3]. The external control system (controller) is used to control the temperature of the system. Since temperature process is extremely a non – linear process. The process given in this paper is a liquid tank with a heater and with two temperature sensors. The temperature sensor used in this process is type RTD, Pt 100[3]. Temperature control systems continuously monitor the inlet temperature of the tank and the outlet temperature of the tank. Typically it contains a controller unit, temperature input unit and control system unit. The Analog to digital (ADC) unit together with measuring unit forms the temperature input unit[4]. The solid state relay (SSR) driver forms the control system unit.

The process is modeled as a first order model based on energy balance equation under the assumption of

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homogenous state of the liquid inside the tank[3]. Here the temperature system also contains a time delay which represents the time delay which in practice exists between heater and the response taken by the sensor. In addition the simulator contains a first order transfer function representing a time constant in the heating element. Thus the process model is modeled as:

Transfer Function: $G(s) = \frac{Ku}{(Ts+1)}\ e^{-}\tau s$

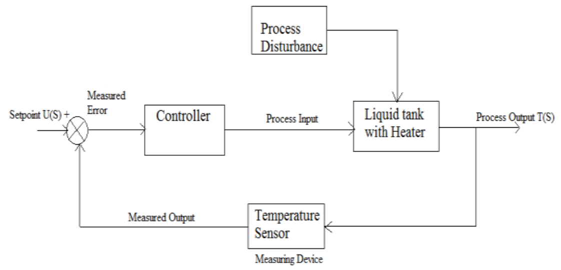

Fig. 1: Temperature Process Block Diagram

Temperatures often have to be set for large machines or systems. The setting should not change when faults occurs. Such tasks are undertaken by the control system, i.e. closed-loop controller (feedback loop). The output variable is first measured and an electrical signal is created to allow an independent closed-loop controller to control the process variable. The measured value in the controller must then be compared with the desired value by the comparator. The result of this comparison is given to the controller, and then the controller determines any action that needs to be taken [9]. Finally an appropriate location must be found in the system where the controlled variable can be inclined. In the temperature process closed-loop system the task is to keep the outlet temperature of the tank at the specific desired range or to follow the desired-value curve.

III. MATHEMATICAL MODELING FOR TEMPERATURE PROCESS

The modeling for a process is a vital role. Modeling is the mathematical representation of the physical system. Building a process model with all physical parameters in the system is called modeling. Precise temperature control is a challenge faced in all process industries. A practical temperature process is a extremely non-linear and slow-moving in nature and the process modeling becomes difficult for larger systems. Figure shown below is a liquid tank with continuous liquid flow. The liquid delivers power through a heater. P is power from the heater. T is temperature inside the liquid tank. T_{inn} is the temperature of the inlet flow [4]. T_{env} is the temperature of the outlet flow. W is at mass flow rate. C is specific heat capacity in the system. ρ is the liquid density. U is total heat transfer coefficients [3]

From the system inputs and outputs parameters, and with some assumptions, such as the inflow rate and the outflow rate of the liquid are equal, and the tank is filled by liquid, there is no storage of thermal energy in the heater[3].

This means that all of the supplied power to the heater is supplied to the liquid inside the tank. The process model for the temperature control system is based on the conservational principle, the energy balance equation for the system, which is given by:

$$\frac{d(C\rho VT(1))}{dt} = K_e u + CW\,(T_{inn}-T_1) + U\,(T_{env}-T_1) \qquad (1)$$

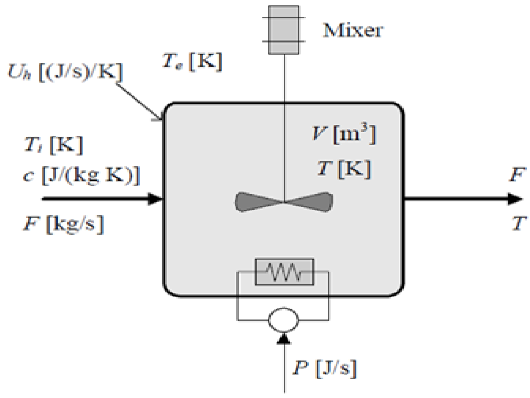

Fig. 2: Liquid tank with heater

In practical application, there is a time delay between an excitation in the heater and the response taken by the temperature sensor [4]. By taking the Laplace transform for the above equation we can get the following transfer function for the system, as control signal to the "Temperature T" is:

$$\frac{T(s)}{U(s)} = H(s) = \frac{Ku}{(Ts+1)}\ e^{-}\tau s \qquad (2)$$

We assumed that this time delay is inversely proportional to the mass flow rate of the liquid. This is a first order model along with time delay processes. Thus for the temperature process model is given by:

$$\frac{T(s)}{U(s)} = \frac{Ku}{(\tau s+1)}\ e^{-tds} \qquad (3)$$

The input heater supply the temperature is allowed to increase from 0°C to the desired level. At each sample time the data from the thermocouple sensor is between 4-20 mA and it is collected and fed to the process by using the serial port RS-232 as an interfacing module. The obtained response from the constant input heater supply is called Process Reaction Curve PRC [9]. From the PRC curve the process is modeled and approximated as First Order plus Delay Time FOPDT process which includes "Gain K", "Time constant τ" and "Dead time td". Then the experimental data are approximated to be a FOPDT model and the acknowledged model of the temperature process as:

$$G(s) = \frac{50}{(30s+1)}\ e^{-tds} \qquad (4)$$

IV. CONVENTIONAL DESIGN TECHNIQUE

A. PID Controller for Temperature Process

The PID controller parameters are given as Kp proportional gain, Ki integral gain and Kd derivative gain. Over the previous fifty years, several methods have been developed for setting the tuning parameters of a PID controller[1]. In this paper it is considered to proceed the Z-N II tuning method. The value of Kp= 0.02835, Ki=0.02831 and Kd=0.0503.

The IMC (Internal Model Control) PID technique is one of the recent long-established tuning techniques that give up improved values among the techniques available for conventional methods [3][4]. For a temperature FOPTD process of the mentioned form in equation (4) Applying the technique for the temperature FOPTD process we get the

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IMC PID tuning parameters as Kp= 0.02975, Ki = 0.000975 and Kd=0.01463.

V. PSO BASED PID CONTROLLER

A. Particle Swarm Optimization

Particle Swarm Optimization is an advance to problems whose solutions can be represented as a point in an n-dimensional solution space. A number of particles are at random set into motion through the space [5]. At each iteration, they study the "fitness" of themselves and their neighbors and "emulate" successful neighbors by moving to them. A different scheme for grouping particles into challenging, semi-independent flock can be used, or all the particles can fit into a single global flock. This simple approach has been amazingly effective across a variety of problem domain. PSO was developed by James Kennedy and Russell in 1995 after being moved by the study of bird flocking behavior by Frank Heppner a biologist[6]. It is associated to evolution-inspired problem solving methods such as Genetic Algorithms (GA).

B. The algorithm

PSO simulates the behaviors of bird flocking. A group of birds are at random probing food in a region. There is only single piece of food in the region being searched [8]. All the birds do not know where the food is located. So what is the best approach to reach the food? The efficient one is to track the bird which is nearest to the food location. PSO is used to solve the optimization problems. In PSO, each single solution is a "bird" in the search space. We call it "particle"[7]. All of particles have fitness range which are calculated by the fitness function and velocities which straight the flying of the particles. The particles fly all the way through the problem space region by follow the present optimum particles [10]. In general the PSO algorithm can be given by the following flowchart, in figure below

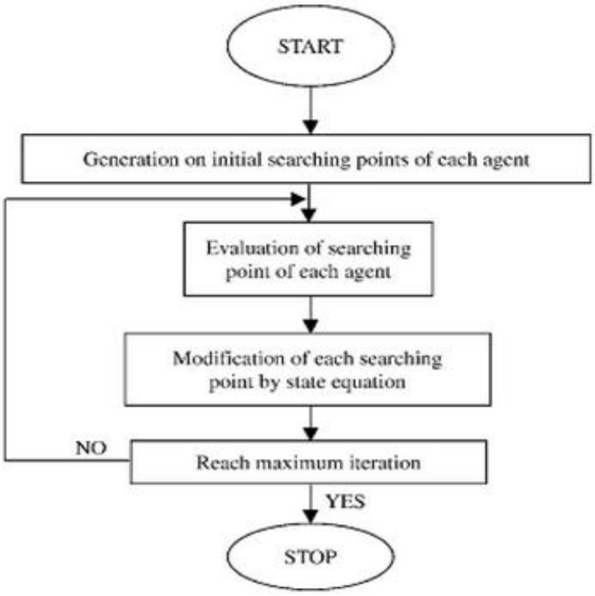

Fig. 3: Flowchart of PSO Algorithm

C. Implementation of PSO Algorithm

The optimal value of the usual PID controller parameters Kp, Ki and Kd is found using PSO techniques [5]. All possible sets of controller tuning parameter values are particles whose values are attuned so as to reduce the main objective functions, which in this case is the error condition. For the PID controller design, it is ensured the optimum controller settings anticipated results in a stable closed loop system.

D. Selection of PSO parameters

To start up with PSO algorithm, some parameters are required. Selection of these parameters decides to a immense level of global minimization. The maximum velocity affects the ability of escaping from local optimization and refining global optimization [6]. The size of swarm balances the requirement of global optimization and computational cost. Initializing the values of the parameters is given in the following table:

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

Table 1.PSO selection parameters

E. Performance Index for the PSO Algorithm

The objective function measured is based on the error principle. The performance of a controller is best evaluated in terms of error principle [11]. A number of such criteria are available and in the proposed work, controller's performance is evaluated in terms of Integral Absolute Errors (IAE) principle that is given by

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

The IAE weights the error with time and hence emphasizes the error values over a range of 0 to T, where T is the settling time.

F. Termination Criteria

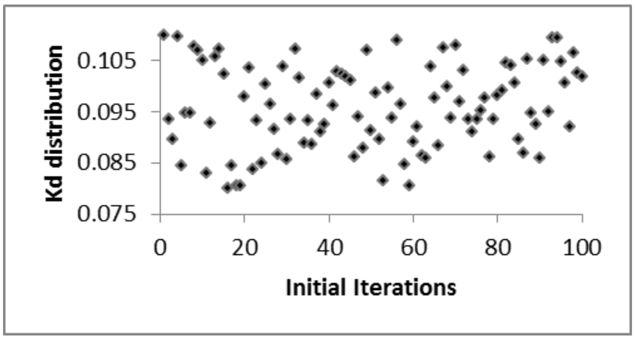

Fig. 4: Distribution of Kd in first iteration

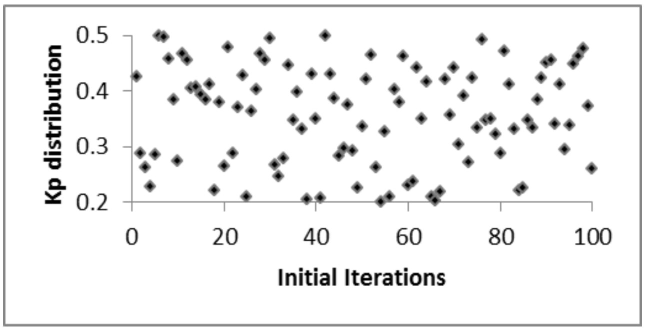

Fig. 5: Distribution of Kp in first iteration

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Termination of optimization algorithm can take place either when the maximum number of iterations gets over [12]. 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 temperature process as shown in Figure 4, 5 & 6. It is clearly seen that the values are well distributed.

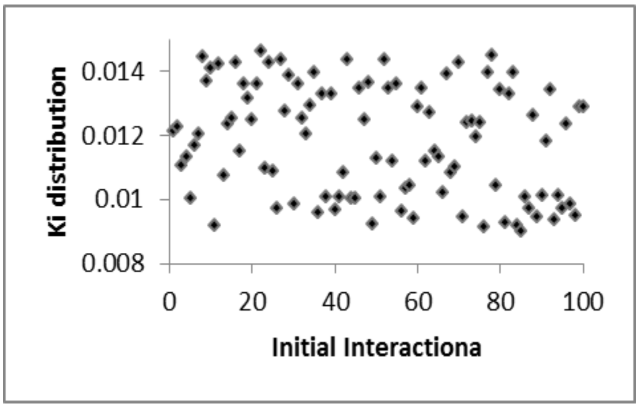

Fig. 6: Distribution of Ki in first iteration

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, Ki and Kd which are shown in figure.7, 8 &.9.

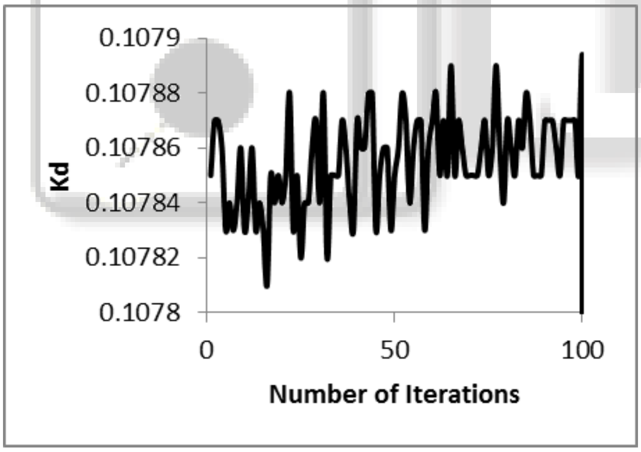

Fig. 7: Best solutions of Kd for 100 iterations.

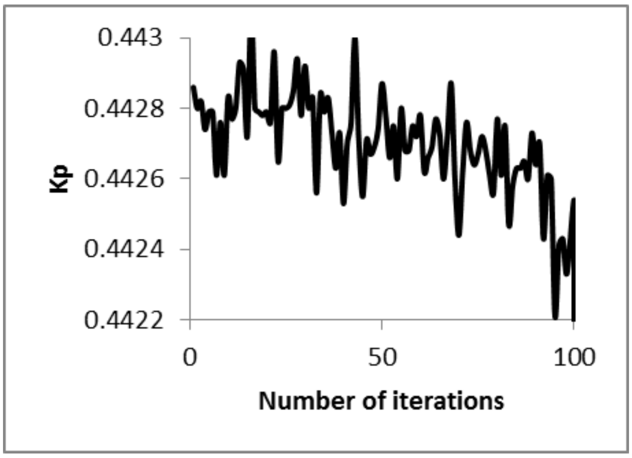

Fig. 8: Best solutions of Kp for 100 iterations.

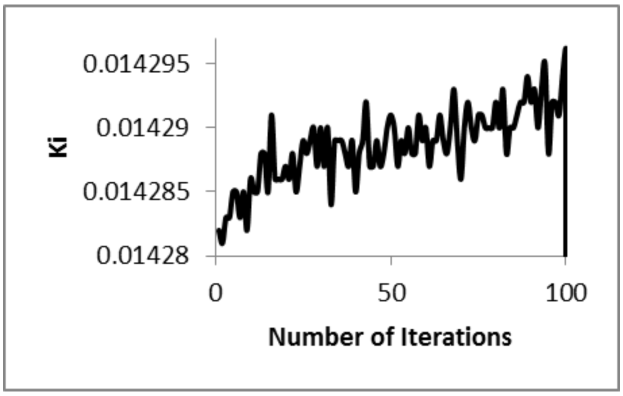

Fig. 9: Best solutions of Ki for 100 iterations.

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. A sketch of the error based on IAE criterion for 100 iterations is given in figure.10.

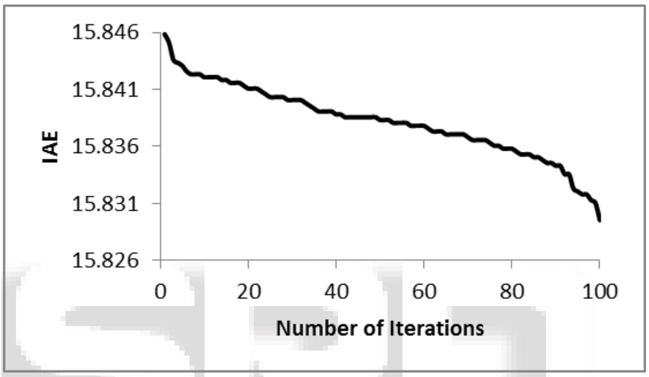

Fig. 10: IAE values for 100 iterations

It was seen 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 PID tuning we get the PID tuning parameters for the temperature process as Kp=0.4425, Ki = 0.0143 and Kd=0.1079.

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

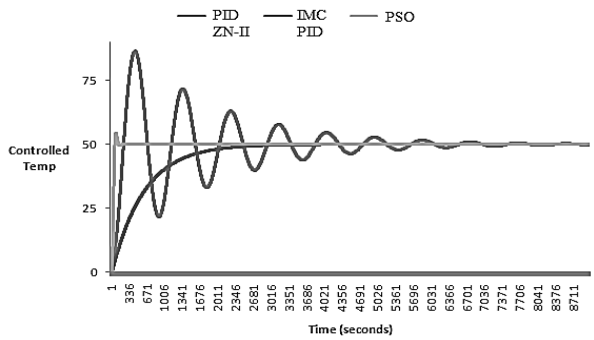

Fig. 11: closed loop response of a temperature process

A tabulation of the time domain specifications comparison and the performance index comparison for the obtained for the temperature process with the designed controllers is

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presented. The response of the temperature process is given in the figure 11.

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 balanced overshoot and settling time. The response of PID and IMC-PID controller is more sluggish than the PSO based controller. The time domain specification comparison is done for the both PID, IMC-PID and PSO based controllers for the responses obtained, is tabulated and given in table.2

	PID ZN-II	IMC controller	PSO controller
Rise time (seconds)	68	35	15
Peak time (seconds)	512	-	10
Overshoot	30	-	2
Settling time (seconds)	7036	2346	250
IAE	208.18	188.78	15.83

Table 2: Comparison of time domain specifications

VII. CONCLUSION

The various results presented prove the betterness of the PSO tuned PID settings than the PID and 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 PID and IMC-PID tuned controller. 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 behavior 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 behavior 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. G. Ziegler and N. B. Nichols, "Optimum settings for automatic controllers," Trans. Amer. Soc. Mech. Eng., vol. 64, pp. 759–768, 1942.
[2] Su Whan Sung, In-Beum Lee and Jitae Lee, "Modified Proportional-Integral Derivative (PID) Controller and a New Tuning Method for the PID Controller", Ind. Eng. Chem. Res., 34, 4127-4132, 1995.
[3] N. Nithyarani and S. Ranganathan, "Advances in Control Techniques and Process Analysis with Lab VIEW and DCS," International Journal of Electronics, Communication & Instrumentation Engineering Research and Development (IJECIERD); Volume: 3; Issue: 2; June 2013.
[4] N. Nithyarani, "Advanced Process Analysis on LabVIEW," International Journal of Advanced Research in Electrical and Electronics Engineering(IJAREEE) Volume 1, Number 1 (November 2013)
[5] Kim, D.H., Abraham, A., Hirota, K., "Hybrid genetic: Particle swarm optimization algorithm", Studies in Computational Intelligence 75, pp. 147-170, Springer-Verlag Berlin Heidelberg,2007
[6] Ren, T., Jing, Y.-W., "ABR traffic control using PSO-PID controller", Journal of Northeastern University 28 (1), pp. 14-18,2007
[7] Wang, J.-S., Zhang, Y., Wang, W., "Optimal design of PI/PD controller for non-minimum phase system" Transactions of the Institute of Measurement and Control 28 (1), pp. 27-35, 2006.
[8] 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.
[9] Rohit Ramachandran, S. Lakshminarayanan and G.P Rangaiah, "Process identification using open-loop and closed loop step responses"Journal of the institute of Engineers,Singapore vol.45,Issue6 2005.
[10] Haibing Hu, Qingbo Hu, Zhengyu Lu, Dehong Xu "Optimal PID controller Design in PMSM Servo System via Particle Swarm Optimization" 31st Annual Conference of IEEE, Industrial Electronics Society, IECON 2005.
[11] N. NithyaRani, Dr. S. M. Giriraj Kumar, Dr. N. Anantharaman, "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.
[12] N. Nithyarani, S. M. Giriraj Kumar "Model Identification of Temperature Process and Tuning with Advanced Control Techniques" International Journal of Innovative Research In Electrical, Electronics, Instrumentation And Control Engineering. Volume 1, Issue 9, December 2013.

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