TUNING OF PID CONTROLLERS USING PARTICLE SWARM OPTIMIZATION

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Abstract- PID controllers are most popular controllers because of simplicity of implementation and broad applicability. In order to obtain the desired control performance correct tuning of PID controller is very important. There are many tuning algorithms available for tuning the PID controller. Most of the tuning processes are implemented manually. These processes are difficult and time consuming. Soft computing techniques have been widely used to tune the parameters of PID. In this paper parameters of PID controller are tuned using soft computing technique which is Particle Swarm Optimization (PSO). The optimal PID control parameters are applied for a composition control system. The performance of the technique is evaluated by setting its objective function with Integral Square Error (ISE), Integral Absolute Error (IAE), Integral of Time multiplied by Absolute Error (ITAE). This paper also compares performance of tuned PID controller using PSO with Ziegler-Nichols method.

Keywords- PID Controller, Ziegler-Nichols method Particle Swarm Optimization.

I. INTRODUCTION

PID controllers are most widely used in industries such as oil and gas, chemical etc. PID controlled has been proven in terms of reliability and robustness in controlling the process variables. Other factors that attracted industries to choose PID could be due low cost, easy to maintain as well as simplicity in control structure and easy to understand. The PID controller calculation involves three separate parameters: proportional, integral and derivative values. The proportional value calculates the value of the current error, the integral value determines the result of sum of recent errors and derivative value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is used to be imported into the controlled system. However in practice, the controlled system systems usually have some features, such as nonlinearity, time-variability and time delay, which make controller parameters tuning more complex. Thus the goal of PID controller tuning is to determine parameter parameters that meet the closed-loop system performance specifications over a wide range of operating conditions. Improper PID parameters tuning could lead to cyclic and slow recovery, poor robustness would be the collapse of system operation [1]. This lead researches to explore the best tuning method in searching optimum PID parameters. Many strategies have been proposed to determine optimum setting of PID parameters. Ziegler-Nichols and cohen-coon are the most popular PID tuning methods. Among the conventional PID tuning methods Ziegler-Nichols (ZN) method may be the well known technique. However sometimes it does not provide good tuning and tends to produce big overshoot. To enhance the capabilities of traditional PID parameters tuning techniques, several soft computing techniques have been suggested, such as those based on Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Differential Evolution (DE), Ant Colony Optimization (ACO).

PSO is a well known simple optimization compared to other optimization techniques. PSO is a novel population-based technique, which utilize the swarm intelligence generated by the cooperation and competition between the particles in a swarm and has emerged as a useful tool for engineering optimization. Unlike other heuristic techniques, it has a flexible and well-balanced mechanism to enhance the global and local exploration abilities.

This paper presents development of an optimal PID controller for a composition control system using PSO technique. This paper also compares the transient performance of the system using PSO technique with Ziegler-Nichols method.

II. COMPOSITE CONTROL SYSTEM

Composite control system was designed to control liquid level in a three tank system. Composite Control system consists control reagent tank, tank1, tank2, tank3. Control

![Composite Control System](image)
Reagent tank contains water and solution. It control the liquid level in tank1, tank2, tank3. Control of liquid level was accomplished by control valve which is operated by PID controller. Liquid flows from control reagent tank to tank1, then tank1 to tank2 and finally tank2 to tank3. The level of liquid in third tank is sent to the controller. The controller generates a signal which opens or closes the control valve. Based on control valve operation liquid level in three tank system is controlled. The time constant and steady state gain of control reagent tank is chosen as 5 and one. The time constant and steady state gain of three tanks is chosen as one. The block diagram representation of the system is shown in fig.2.

Where R is the set-point, C is the output of three tanks that is height of liquid level and Ci is the input from the control reagent tank. The transfer function of the system shown in fig.2 is

\[ C(s) = \frac{1}{(5s + 1)(s + 1)^3} + \frac{1}{(s + 1)^3} \]  

Many methods are available for tuning the PID controller. The most widely used method is Ziegler-Nichols method. Though Ziegler-Nichols method is simple and most popular it has some disadvantages. It gives large overshoot and prior knowledge regarding plant model. If the plant is tuned by the Ziegler-Nichols method it gives good results but those are not optimum. To enhance the PID parameter tuning techniques soft computing techniques have been suggested. Some of the techniques are Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Differential Evolution (DE), Ant Colony Optimization (ACO).

III. PID CONTROLLER

PID controller consists of three separate PID controller consists of three separate parameters: proportional, integral and derivative with gains denoted by Kp, Ki, Kd. Appropriate setting of these parameters will improve dynamic response of a system, reduce over shoot eliminate steady state error and increase stability of the system. The transfer function of a PID controller is

\[ C(S) = \frac{K_p + K_i}{s} + K_dS \]  

Once the input has been changed, the error will be computed between the input and actual output. The error signal, E(s), is used to generate the proportional, integral, and derivative actions. With the resulting signals weighted and summed to form the control signal U(s), applied to the plant model. The new output signal will be obtained. This new actual output signal will be sent to the controller, and again error signal will be computed. New control signal, U(s) will be sent to the plant. This process will run continuously until the steady state error.

![PID Control Structure](image)

IV. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization, first introduced by Kennedy and Eberhart, is one of optimization algorithms. It was developed through simulation of simplified social system, and has been found to be robust in solving continuous nonlinear optimization problems. PSO can generate a high quality solution within shorter calculation time and stable convergence characteristic than other stochastic methods.

PSO is a population based stochastic optimization technique where individuals, referred to as particles, are grouped into a swarm. Each particle in the swarm represents a candidate solution to the optimization problem. In PSO technique each particle is flown through a multidimensional search space, adjusting its position in search space according to its own experience and that of neighboring particles. A particle therefore makes use of best position encountered by itself and that of its neighbors to position itself toward an optimal solution. The effect is that particles fly toward a minimum, while still searching a wide area around the best solution. The performance of each particle is measured using a predefined fitness function, which encapsulate the characteristics of the optimization problem.

Algorithm of PSO is as follows

Step-1: Set up the control parameters of PSO optimization process that are population size, acceleration constants(C1,C2), convergence criterion, number of problem variables, lower and limits of variables and maximum number of iterations. Create an initial population of particles with random positions and velocities. The positions (x_k) and velocity(v_k) of initial swarm of the particle are
randomly generated using lower and upper bounds of design variables. For ith particle position and velocity are generated as follows

\[
X_i^k = X_{min} + (X_{max} - X_{min}) \cdot \text{rand} \quad (2)
\]
\[
V_i^k = V_{min} + (V_{max} - V_{min}) \cdot \text{rand} \quad (3)
\]

Step-2: For each particle calculate the value of fitness function.

Step-3: Compare the fitness of each particle with personal best position (pbest). If current solution has best fitness then replace pbest with current fitness.

Step-3: Compare the fitness of all particles with global best (gbest). If any of the particles is better than gbest, and then replace gbest.

Step-4: Update the velocity and positions of all particles. The velocity of ith particle is updated as

\[
V_{i}^{k+1} = V_{i}^k + c1 \cdot r1 \cdot (P_{best} - X_i^k) + c2 \cdot r2 \cdot (C_{best} - X_i^k) \quad (4)
\]

Where \( V_i^k \) is the velocity of ith particle at time k. \( c1, c2 \) are acceleration constants. \( r1, r2 \) are random variables, \( P_{best} \) is personal best position of ith particle at time \( k \). \( C_{best} \) is the global best position of ith particle. \( X_i^k \) is the position of ith particle at time \( k \).

The position of the particle is updated as

\[
X_i^{k+1} = X_i^k + V_i^{k+1} \quad (5)
\]

Step-5: Repeat the steps from 2 to 4 until the desired fitness is reached.

![Flow Chart of Particle Swarm Optimization](image)

**V. EVALUATION OF FITNESS FUNCTION**

The fitness function considered here is based on error criterion. This work utilizes performance indices as objective function. Controller performance is evaluated in terms of integral square error (ISE), integral absolute error (IAE), integral time multiplied by absolute error (ITAE). PID controller is tuned based on the minimum value of performance index.

\[
I_{ISE} = \int_0^T e^2(t) \cdot dt \quad (6)
\]
\[
I_{IAE} = \int_0^T |e(t)| \cdot dt \quad (7)
\]
\[
I_{ITAE} = \int_0^T |t|e(t)| \cdot dt \quad (8)
\]

**VI. IMPLEMENTATION PID CONTROLLER TUNING**

In this section the performance of composite control system with Ziegler-Nichols method, PSO and HDE is evaluated. The tuning performance is evaluated using integral square error (ISE), integral absolute error (IAE), integral of time multiplied by absolute error (ITAE). PSO and HDE find optimum value of control parameters where the smaller the value of fitness function. The transient performance of the system tuned by PSO and HDE is compared with Ziegler-Nichols method.

**A. PID TUNING WITH ZIEGLER NICHOLS METHOD**

Ziegler-Nichols tuning method is the first tuning method to provide a practical approach for tuning of PID controller. This tuning rule is very popular in industry as it is a simple method and it requires very little information about the process.

However the resulting system may exhibit large overshoot and oscillations in the step response which is unacceptable. In fact Ziegler-Nichols tuning rules give an educated guess for the parameter values. Tuning of PID controller using Ziegler-Nichols is based on frequency response of closed-loop system by determining the point of marginal stability under pure proportional control.

The proportional gain is increased until the system becomes marginal stable. At this point, the value of proportional gain is known as ultimate gain \( k \) together with its period of oscillation frequency so called ultimate period \( \tau_u \). Based on these values tuning parameters are calculated as shown in table 1

<table>
<thead>
<tr>
<th>Controller</th>
<th>( K_p )</th>
<th>( K_i )</th>
<th>( K_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>PID</td>
<td>0.6*k</td>
<td>2k/\tau_u</td>
<td>( K^* \tau_u/8 )</td>
</tr>
</tbody>
</table>

For mathematical model system the ultimate gain and ultimate period can be calculated using Routh-
The PID tuning parameters are calculated and those are $K_p = 3.7$, $K_i = 1.8$ and $K_d = 1.8$.

VII. SIMULATION RESULTS

In this section PSO is applied to find the optimal parameters of PID controller for the closed loop controlled composite control system. The parameter values of PSO and HDE optimization are shown in Table 2. The performance of tuning method is observed in terms of rise time, overshoot, peak time, settling time and steady state error.

Table 2

<table>
<thead>
<tr>
<th>Parameter Setting for PSO</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Size</td>
<td>80</td>
</tr>
<tr>
<td>Generation Size</td>
<td>220</td>
</tr>
<tr>
<td>Range of $K_p$</td>
<td>40</td>
</tr>
<tr>
<td>Range of $K_i$</td>
<td>20</td>
</tr>
<tr>
<td>Range of $K_d$</td>
<td>200</td>
</tr>
<tr>
<td>$C_1$</td>
<td>2</td>
</tr>
<tr>
<td>$C_2$</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>Objective Function</th>
<th>ZN</th>
<th>GA</th>
<th>PSO-ISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage overshoot</td>
<td>44.2823</td>
<td>20.8564</td>
<td>17.3499</td>
</tr>
<tr>
<td>Rise Time (Sec)</td>
<td>0.9586</td>
<td>0.6619</td>
<td>0.6817</td>
</tr>
<tr>
<td>Peak Time (Sec)</td>
<td>2.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Settling Time (Sec)</td>
<td>10.4349</td>
<td>6.7159</td>
<td>3.5141</td>
</tr>
<tr>
<td>Steady State Error</td>
<td>16.841*10^{-4}</td>
<td>9.184*10^{-4}</td>
<td>1.489*10^{-4}</td>
</tr>
</tbody>
</table>

Figures 5 to 8 illustrate the optimization process with PSO and the closed loop step response with ISE and IAE objective functions.
Table 4

<p>| Response Characteristics of the system for a unit step response with IAE objective function |
|----------------------------------|-----------|-----------|</p>
<table>
<thead>
<tr>
<th>ZN</th>
<th>GA</th>
<th>PSO-IAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>%age overshoot</td>
<td>44.2823</td>
<td>27.4646</td>
</tr>
<tr>
<td>Rise Time(Sec)</td>
<td>0.9586</td>
<td>0.6276</td>
</tr>
<tr>
<td>Peak Time(Sec)</td>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td>Settling Time(Sec)</td>
<td>10.4349</td>
<td>2.6804</td>
</tr>
<tr>
<td>Kp</td>
<td>3.7</td>
<td>31.1642</td>
</tr>
<tr>
<td>Ki</td>
<td>1.8</td>
<td>9.0578</td>
</tr>
<tr>
<td>Kd</td>
<td>1.8</td>
<td>92.0436</td>
</tr>
</tbody>
</table>

It is clear from the responses that the PSO based controller has the advantage of a better closed loop rise time, settling time, over shoot and steady state error compared to the Ziegler-Nichols method. The time domain specification comparison is done for the ZN and PSO-ISE, PSO-IAE and PSO-ITAE based controllers are tabulated and given in Table 3, Table 4, and Table 5.

CONCLUSION

PID controller has been tuned using Ziegler-Nichols method and Particle Swarm Optimization for a composite control system. The various results presented above proves better performances of PID controller tuned with PSO than PID controller tuned with Ziegler-Nichols method. The step responses for the system reflect effectiveness of the PSO based PID controller in terms of time domain specifications. The results show that the proposed controller can perform an efficient search for the optimal PID controller parameters.

REFERENCES


Induction motor speed control” University of Sciences and Technology of Oran, Algeria, August 2007.

