Genetic Algorithms Based Intelligent Control Technique for Rotating Electrical Machine

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Abstract—The demand for high-performance control of motor drives is rapidly increasing, particularly in the area of traction, electric vehicles and industry. Artificial intelligent controller (AIC) could be the best candidate for Motor control. The main aim of this paper is to analyse the implementation of Artificial intelligent (AI) techniques viz. Genetic Algorithm (GA) for optimal tuning of PID controllers parameters and enumerate their advantages over the conventional tuning methodologies. The technique was implemented and analysed on a third order plant model of a DC servomotor with the aim of developing a position controller. The results obtained from GA algorithm were compared with that obtained from Ziegler Nichols method. It was found that the Genetic Algorithms outperformed traditional tuning practices of Zeigler-Nichols at tuning of PID controllers.

Keywords—Intelligent Control, DC Servo motor, PID controller, PID Tuning, Ziegler Nichols (ZN), Genetic Algorithm (GA).

I. INTRODUCTION
In process control industry, majority of control system loops are based on Proportional-Integral-Derivative (PID) controllers. PID controllers are being widely used in industry due to their well-grounded established theory, simplicity, maintenance requirements, and ease of tuning. The basic structure of the PID controllers makes it easy to regulate the process output. Therefore, efficient design and tuning methods leading to an optimal and effective operation of the PID controllers in order to regulate the different parameters of the plant are economically vital for process industries. The main goal of this paper is to analyse the implementation intelligent technique viz. Genetic Algorithm (GA) for optimal tuning of PID controllers parameters and enumerate their advantages over the conventional tuning methodologies. Genetic Algorithms (GA) are adaptive heuristic search based on evolutionary ideas of natural selection and genetics. Genetic Algorithms are effective and intelligent choice at finding the best solution among the space of all feasible solutions. Genetic Algorithms were used to evaluate the optimum PID controller gain values where performance indices ITAE, IAE, ISE and MSE were used as the objective functions. The proposed methodology was verified using a third-order physical plant (Armature-controlled DC servomotor position control system) where tuning algorithms were driven mainly by the acquired system data and the desired performance parameters specified by the user are successfully satisfied. Resultant improvements on the step response behaviour of DC servomotor position control system are shown for two cases.

II. SYSTEM MODELLING
As a reference we consider armature controlled DC servomotor as shown in Figure 1. In the point of control system, DC servo motor can be considered as linear SISO plant model having third order transfer function. The DC servomotors are found to have an excellent speed and position control. A simple mathematical relationship between the shaft angular position \( \theta \) and voltage input \( V_a(t) \) to the DC motor may be derived from physical laws.
which may be expressed as

The armature current is related to the input voltage applied to the armature by

In Laplace transform notation, the motor torque is

The armature current is related to the input voltage applied to the armature by

where \( T \) is the load torque and \( T_d \) is the disturbance torque which is often negligible, so

Therefore, the transfer function of the motor load combination, with \( T_d = 0 \), is:

Here the angular displacement \( \theta(s) \) is considered the output and the armature voltage \( V_a(s) \) is considered the input. The block diagram representation is shown in figure 2.

![Block Diagram representation of a DC Servo motor](image)

**III. PID CONTROLLER**

The PID controller, represented by Fig.2, is well known and widely used to improve the dynamic response as well as to reduce or eliminate the steady state error. The Derivative controller adds a finite zero to the open loop plant Transfer function and improves the transient response. The Integral controller adds a pole at the origin, thus increasing the system type by one and reducing the steady state error due to a step function to zero. PID controller consists of three types of control Proportional, Integral and Derivative control [6].

\[
\frac{\theta(s)}{V_a(s)} = \frac{k_m}{s[(L_a s + R)(Js + b) + (k_a k_b)]}
\]

\[
\theta(s) = \frac{k_m}{L a s^3 + (L b + R) s^2 + (R b + k_a k_b)s}
\]

Appendix A, the overall transfer function of the system is given as:

\[
V_a(s) = 0.005s^2 + 0.06s^2 + 0.1001s
\]

\[
\theta(s) = 0.01
\]
The PID controller output relating the error can be described by,

\[ u(t) = k_p e(t) + k_i \int_0^t e(t) dt + k_d \frac{de(t)}{dt} \]

where \( e(t) \) is the error, \( u(t) \) the controller output, and \( k_p, k_i, k_d \) are the Proportional, Integral and Derivative gains.

In the frequency domain, the relation between the controller input \( E \) (error signal) and output \( U \) (input to the plant) can be expressed by the following transfer function:

\[ G_C(S) = \frac{U(S)}{E(S)} = \frac{k_i}{s} + k_d s \]

The closed loop transfer function is given by,

\[ Y(S) = \frac{G_C(S)G(S)}{1 + G_C(S)G(S)} \]

The tuning of a PID controller consists of selecting gains \( K_p, K_i, K_d \) so that performance specifications are satisfied.

### IV. TUNING OF PID CONTROLLER USING CONVENTIONAL APPROACH

#### A. Conventional Approach - Ziegler Nichols Method

Ziegler-Nichols (ZN) method for tuning of PID controllers, though a classic method, has been widely used for the design of various controllers. Ziegler and Nichols presented two methods, a step response method and a frequency response method. In this paper we have employed the frequency response method for tuning of the PID controller.

#### B. Implementation of ZN based PID controller

In this method, the integral time \( T_i \) will be set to infinity and the derivative time \( T_d \) to zero. This is used to get the initial PID setting of the system. Thus the proportional control is selected alone. Increasing the value of the proportional gain, \( K_p \), until the point of instability is reached (sustained oscillations), gives the critical value of gain, \( K_c \). Thereafter measurement of the period of oscillation of the response is used to obtain the critical time constant, \( T_c \).

Once the values for \( K_c \) and \( T_c \) are obtained, the PID parameters can be calculated, according to the design specifications, as given in Table 1. Further the values of the PID gain coefficients \( K_p, K_i \) and \( K_d \) for the system described by equation (3), obtained after simulation in MATLAB are given in Table 2.

#### Table 1 Ziegler-Nichols PID tuning parameters

<table>
<thead>
<tr>
<th>CONTROLLER</th>
<th>( K_p )</th>
<th>( T_i )</th>
<th>( T_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P )</td>
<td>0.5( K_c )</td>
<td>Inf</td>
<td>0</td>
</tr>
<tr>
<td>( PI )</td>
<td>0.45( K_c )</td>
<td>0.833( T_c )</td>
<td>0</td>
</tr>
<tr>
<td>( PID )</td>
<td>0.6( K_c )</td>
<td>0.5( T_c )</td>
<td>0.125( T_c )</td>
</tr>
</tbody>
</table>

**Table 2 Ziegler-Nichols PID tuning values**

<table>
<thead>
<tr>
<th>Gain Coefficients</th>
<th>( K_p )</th>
<th>( K_i )</th>
<th>( K_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values</td>
<td>72.0720</td>
<td>102.6374</td>
<td>12.6486</td>
</tr>
</tbody>
</table>

From the above formulation the step response of the overall system with conventionally tuned PID controller is shown in Fig.4.

**Fig 5 Step Response of DC Motor with ZN Tuned PID**

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**IV. GENETIC ALGORITHMS**

#### A. Overview

Fig 5 Step Response of DC Motor with ZN Tuned PID
 beings: natural selection and genetic. The simplest form of genetic algorithm involves three types of operators: selection, crossover, and mutation. GAs are population-based search methods that work through the following elements: populations of chromosomes, selection according to fitness, crossover to produce new offspring, and random mutation of new offspring.

The GA process consists in an iterative stepwise refinement of the performance of the individuals. The first step is the creation of a new population composed of individuals randomly generated. Then a fitness function evaluates and assigns to each individual a performance measure, or fitness value. The definition of the fitness function depends on the objective function. Then this population evolves for a number of iteration called generation until to satisfy a termination criterion.

![Block diagram for PID parameters tuning using GA.](image)

**Fig.4  Block diagram for PID parameters tuning using GA.**

**B. GA-Based PID Controller Optimization**

1) GA Tuning Parameters

The values in the Table 1 describe the GA settings used for this work.

**TABLE 3: GA Tuning Parameters**

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower bound [Kp Ki Kd]</td>
<td>[0 0 0]</td>
</tr>
<tr>
<td>Upper bound [Kp Ki Kd]</td>
<td>[100 100 100]</td>
</tr>
<tr>
<td>Stopping criteria (Iterations)</td>
<td>100</td>
</tr>
<tr>
<td>Population Size</td>
<td>40</td>
</tr>
<tr>
<td>Crossover Fraction</td>
<td>4</td>
</tr>
<tr>
<td>Mutation Fraction</td>
<td>0.08</td>
</tr>
</tbody>
</table>

2) Steps in GA-Based PID Controller Optimization

**Step 1** Establish initial population of individuals

An initial random population having P(t) individuals is generated.

**Step 2** Evaluate the fitness of each individual in P(t)

Evaluate all the individual solutions with the fitness function, which can be the inverse of error function.

**Step 3** Select some highly fit solutions

Select P'(t+1) form intermediate population of fittest members from initial population P(t).

**Step 4** Apply crossover to selected solutions

Pair off and mate individuals in P'(t+1) as parents and perform crossover operation to generate offsprings.

**Step 5** Apply mutation

Perform mutation by slightly changing some random solution.

**Step 6** Steps 2–5 are repeated until the predefined value of the function or the number of iterations has been reached. Record the optimized Kp, Ki and Kd values

**Step 7** Perform closed-loop test with the optimised values of controller parameters and calculate the time domain specification for the system.

![Fig.6 Convergence of Genetic Algorithm](image)
Fig. 6 shows the convergence of genetic algorithm through various generations for the three PID parameters, \( K_p \), \( K_i \) and \( K_d \). Fig. 7 shows the step response of GA tuned controller parameter.

V. SIMULATION RESULTS

In order to improve the performance of the dc motor under transient and steady state condition, a PID controller is inserted in the forward path as shown in Fig 4. The parameters of the PID controller are now adjusted by using conventional method i.e. Ziegler-Nichols method and the response obtained for the DC servomotor is evaluated. Further again the parameters of PID controller are obtained using evolutionary computation of GA and the system step responses are evaluated.

The controller gains were computed by using the classical Zeigler-Nichols rules and evolutionary computation techniques i.e. Genetic Algorithm. The controller gains obtained from the methods are listed in Table 3.

| TABLE 4: Comparison of steady state responses |
|-----------------|-----------------|-----------------|
| **TITLE**       | **ZN_PID**      | **GA_PID**      |
| Rise Time (sec) | 0.2901          | 0.1070          |
| Settling Time (sec) | 5.0139        | 1.0721          |
| % Overshoot     | 61.7409         | 21.3911         |
| Peak Time (sec) | 0.8492          | 0.2395          |
| \( K_d \)       | 12.6486          | 99.0720         |
| \( K_p \)       | 72.0720          | 91.7813         |
| \( K_i \)       | 102.6374         | 1.3092          |

The comparative output responses of the system tune using GA-based PID controller and conventionally tuned PID controller using Zeigler Nichols (ZN) method is shown in figure 8. The GA tuned system exhibits greatly reduced overshoot, rise time and settling time.

VI. CONCLUSIONS

In this paper, two different control techniques are used for the tuning controller which are, conventional Ziegler Nichols Method and Intelligent control technique(GA). Application of Intelligent technique (GA) to the optimum tuning of PID controller led to a satisfactory close-loop response for the system under consideration. Comparison of the results as shown in Table 4 clearly shows that the GA controller shows fast control response with DC Servo motor. The GA tuned system reduced overshoot, rise time and settling time. The same Intelligent technique(GA) can be implemented with the Induction motor drive for analysis of dynamic response.

REFERENCES

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APPENDIX A: SYSTEM MODEL
PARAMETERS

The parameters of the DC servomotor under consideration are as follows:

- \( J \) moment of inertia of the rotor = 0.01 kg.m\(^2\)
- \( b \) motor viscous friction constant = 0.1 N.m.s
- \( k_v \) back emf constant = 0.01 V.rad/sec
- \( k_m \) motor torque constant = 0.01 N.m/Amp
- \( R \) electric resistance = 1.0 Ohm
- \( L_a \) electric inductance = 0.5 H

NOMENCLATURE

- \( i_a \) Armature current in ampere,
- \( i_f \) Field current in ampere,
- \( k_m \) Motor torque constant,
- \( k_b \) Back emf constant,
- \( V_a \) Armature voltage in volts,
- \( V_b \) Back emf in volts,
- \( J \) Moment of inertia of rotor,
- \( b \) Viscous frictional constant of motor,
- \( \theta \) Angular displacement of shaft in radians,
- \( L_a \) Armature inductance in henry,
- \( R_a \) Armature resistance in ohm
- \( C \) Positive acceleration constants (0–2)
- \( G_c (S) \) Controller model
- \( G_P (S) \) Process model
- \( IAE \) Integrated absolute error
- \( ISE \) Integral squared error
- \( ITAE \) Integral time absolute error
- \( MSE \) Mean square error
- \( k_p \) Proportional gain
- \( k_i \) Integral gain
- \( k_d \) Derivative gain
- \( R \) Random number (0-2)
- \( R(s) \) Reference input
- \( Y(s) \) Process output