IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

Impact Factor: 6.252

Volume 2, Issue 3, May 2022

Optimal Tuning of PID Controller to Control speed of DC Motor Using PSO Algorithm

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Abstract: *DC motor is an electrical machine which is used in many day to day life applications. So, it is essential to control the speed for various applications. In this paper, to control the speed of DC motor, tuning of PID controller parameters are considered using Particle Swarm Optimization (PSO) and Zeigler-Nichol's (ZN) methods. The main objective of this paper is to minimize the Overshoot, Steady State Error, Rise time and settling time by finding the optimum value of Proportional Gain (Kp), Integral Gain (Ki) and Derivative Gain (Kd). PSO algorithm is population based technique where population size (space), initial velocity, location and direction are randomly allotted and based on these parameters reached to optimal solution. PSO algorithm gives more optimum value of Kp, Ki and Kd as compared to ZN method. Matlab Simulink software is used for experimentation and optimization of DC motor model. It gives the graphical representation of output and respective analysis done through it.*

Keywords: DC Motor, Particle Swarm Optimization (PSO), Ziegler-Nichols Tuning Method, PID Controller.

I. Introduction

PID controllers are one of the most applicable controllers in different industries. Its widespread use and universal acceptability is attributed to its simple operating algorithm, the relative ease with which the controller effects can be adjusted, the broad range of applications where it has reliably produced excellent control performances, and the familiarity with which it is perceived amongst researchers and practitioners within the process control community. The main important need in application of these controllers is their parameters tuning in order to gain desired result. Existing tuning rules for their design are usually based on trial and error which are so time consuming, not accurate and have considerable error. So an accessible method with high accuracy and speed has to be used for determination of these control parameters (Kp, Ki, Kd).

Particle swarm optimization (PSO) has attractive features like, ease of implementation and the fact that no gradient information is required. It can be used to solve a wide array of different optimization problems [1].PSO algorithm is a population algorithm based on principles of natural selection and search algorithm. There are many evidences of intelligence for the posed domains in animals, plants, and generally living systems [2].Unlike the other heuristic techniques, PSO has a flexible and well-balanced mechanism to enhance the global and local exploration abilities [3].

In this paper, an optimal PID-PSO controller and PID-ZN controller are developed for DC motor speed control. The performance measure to be minimized contains the following objectives of the PID controller, that will be studied separately,

1. **Minimize the rise time**, time required for systemresponse to rise from 10% to 90% (over damped); 5% to 95%; 0% to 100% (Under damped) of the final steady state value of the desired response,
2. **Minimize the maximum overshoot**, Maximum overshoot is the maximum peak value of the response curve measured from the desired response of the system, and
3. **Minimize the settling time**, Time required for response to reach and stay within 2% of final value.
4. **Minimize the steady state error**, the difference between the input and output of the system in the limit as time goes to infinity, i.e. when the transient response reaches a steady state. With no overshoot the steady state error is eliminated when the steady state velocity of the DC motor reaches the desired velocity.

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II. DC Motor Model

In armature control of separately excited DC motors, the voltage applied to the armature of the motor is adjusted without changing the voltage applied to the field [8]. Figure 1 shows equivalent DC Motor Model.

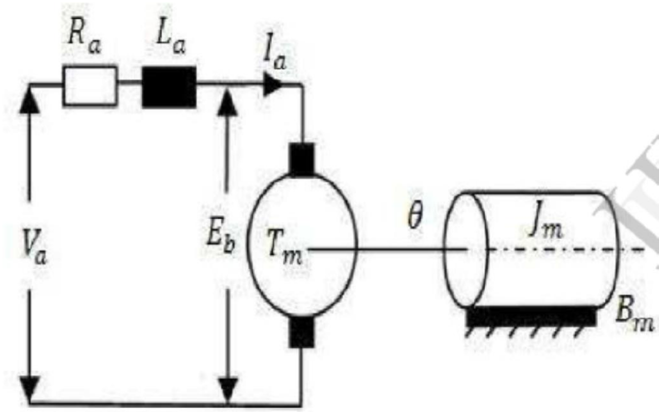

Figure 1: DC Motor Model

The important expressions of DC Motor are:

$$V_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + E_b(t) \qquad \text{... (1)}$$

$$E_b(t) = K_{b\omega}(t) \qquad \text{... (2)}$$

$$T_m(t) = K_t i_a(t) \qquad \text{...(3)}$$

$$T_m(t) - T_L(t) = J_m B_m \omega(t) \qquad \text{...(4)}$$

where Va= armature voltage (V), Ra = armature resistance (Ω), La = armature inductance (H), Ia= armature current (A), *Eb*= Back emf (V), ω = angular speed (rad/sec), Tm = motor torque (Nm), TL= load torque (Nm), θ = angular position of rotor shaft (rad), Jm= rotor inertia (kgm2), Bm= viscous friction coefficient (Nms/rad), Kt= torque constant (Nm/A), Kb = Back emf constant (Vs/rad). Figure 2 showing the basic block diagram of DC motor model including their transfer functions. Vais the input supply, TL is load torque and ω is angular speed.

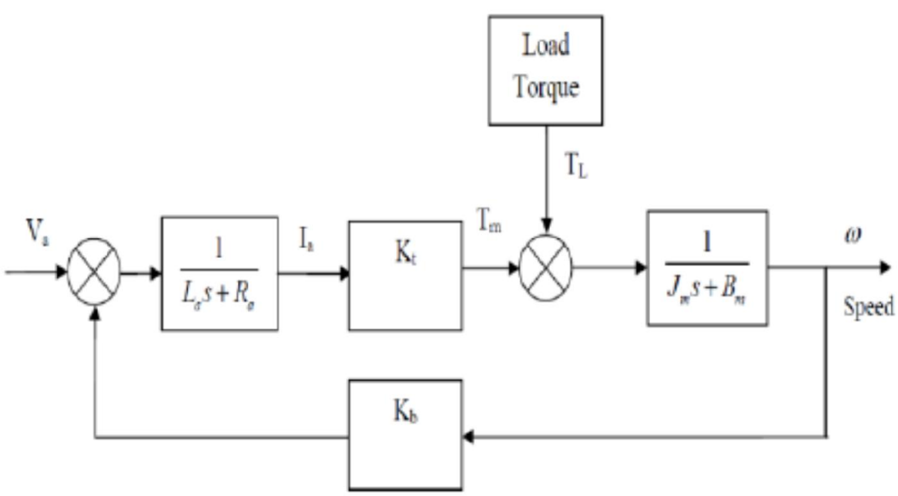

Figure 2: Block Diagram of DC Motor Model

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III. PID CONTROLLER

The PID controller is the most common general purpose controller in the today‘s industries. It can be used as a single unit or it can be a part of a distributed computer control system [5-8]. After implementing the PID controller, now we have to tune the controller; and there are different approaches to tune the PID parameters like P, I and D. The Proportional (P) part is responsible for following the desired set-point while the Integral (I) and Derivative (D) part account for the accumulation of past errors and the rate of change of error in the process or plant, respectively.

PID controller consists of three types of control i.e. Proportional, Integral and Derivative control. Figure 3 Shows the Schematic PID Controller

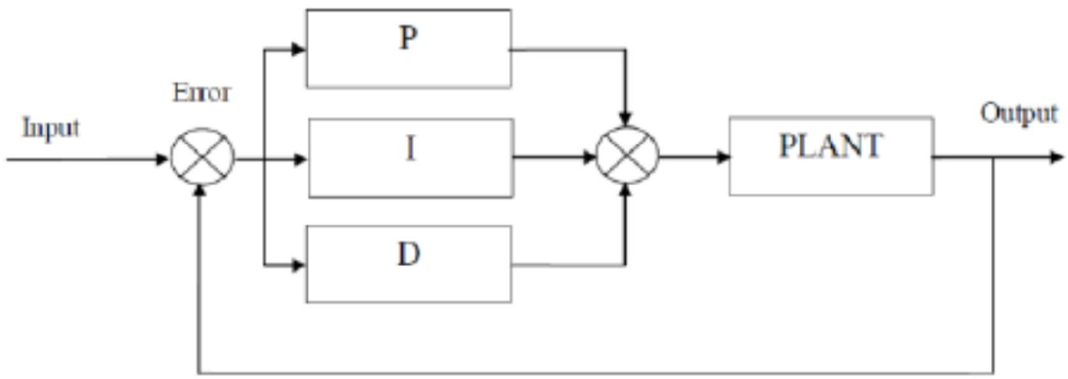

Figure 3: Schematic PID Controller

$$u(t) = P + I + D \qquad ...(5)$$

$$P = K_p e(t) \qquad ...(6)$$

$$I = K_i \int e(t)dt \qquad ...(7)$$

$$D = K_p \frac{de}{dt} \qquad ...(8)$$

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_p \frac{de}{dt} \qquad ...(9)$$

Where, u(t) = PID Output, Kp = Proportional Gain, Ki = Integral Gain, Kd = Derivative Gain, e(t) = Error Value, de = Change in error value, dt = Change in time

.

IV. ZIEGLER NICHOLS METHOD

This method is applied to plants with step responses of the form displayed in Fig. 5. This type of response is typical of a first order system with transportation delay. The response is characterized by two parameters, *L* the delay time and *T* the time constant. These are found by drawing a tangent to the step response at its point of inflection and noting its intersections with the time axis and the steady state value. The plant model is therefore,

$$G(s) = \frac{K_{e^{-sL}}}{TS+1} \qquad ...(10)$$

Standard Gain chart estimated by Ziegler Nichol’s as shown in Table 1.

Table 1: Ziegler Nichols Tuning Method

Type of Controller	Proportional Gain(Kp)	Reset Time (Ti)	Rate Time (Td)
P	0.5Kcr	Infinity	0
PI	0.45Kcr	1/1.2Pcr	0
PID	0.6Kcr	0.5Pcr	0.125Pcr

Where, Kcr = Critical Value of Proportional Gain
Pcr = Period of Sustained Oscillation

The way to determine the value of Kcr and Pcr, manually adjusting and spotting the graph for every estimation and finalized its value at sustained oscillations.

V. Calculation of Kp, Kd and Ki by Ziegler Nichol's Method

Transfer Function of PID Controller,

$$G(s) = Kp + \frac{1}{Ti*s} + Td*s \qquad ...(11)$$

$$G(s) = Kp\left(1 + \frac{Ki}{Kp} + \frac{Kd*s}{Kp}\right) \qquad ...(12)$$

Comparing above two equations,

$$\frac{Ki}{Kp} = \frac{1}{Ti} \qquad Ki = \frac{Kp}{Ti}$$

$$\frac{Kd}{Kp} = Td \qquad Kd = Kp*Td$$

Standard Estimation given by Ziegler for PID Parameter,

Figure 4 shows graphical representation of Pcr and Kcr Values as:

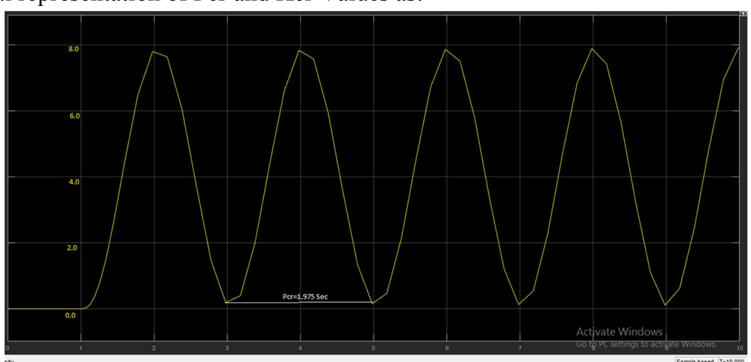

Fig. 4 Graphical representation of Pcr and Kcr

Kp=0.6 Kcr, Ti=0.5 Pcr and Td=0.125Pcr

Where Kcr=7.5 and Pcr=1.975 Sec (Values taken from Graph)

Kp=0.6*7.5=4.5

$Ki=Kp/Ti$=(0.6∗7.5)/(0.5∗1.975)=4.557

Kd=Kp*Td=0.6*7.5*0.125*1.975=1.111

Therefore,

Proportional Gain (Kp)=4.5

Integral Gain (Ki)=4.557

Derivative Gain(Kd)=1.111

5.1 Particle Swarm Optimization Method

Namely, PSO is basically developed through simulation of bird flocking in two-dimension space. The position of each agent is represented by XY axis position and also the velocity is expressed by Vx (the velocity of X axis) and Vy (the velocity of Y axis). Modification of the agent position is realized by the position and velocity information [1-5].

Bird flocking optimizes a certain objective function. Each agent knows its best value so far (pbest) and its XY position. This information is analogy of personal experiences of each agent. Moreover, each agent knows the best value so far in the group (gbest) among pbests. This information is analogy of knowledge of how the other agents around them have performed. Namely, Each agent tries to modify its position using the following information:

- The current positions (x, y),
- The current velocities (vx, vy),
- The distance between the current position and pbest

- The distance between the current position and gbest

This modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following equation:

$$V_i^{k+1} = WV_i^k + C_1 rand_1 X\left(pbest_i - S_i^k\right) + C_2 rand_2 X\left(gbest_i - S_i^k\right) \quad \ldots(11)$$

Where, V_i^k : Velocity of agent i at iteration k,
W: weighting function,
Cj : weighting factor,
rand: random number between 0 and 1,
S_i^k : Current position of agent i at iteration k,
pbesti : pbest of agent i,
gbest: gbest of the group.

Using the above equation, a certain velocity, which gradually gets close to pbest and gbest can be calculated. The current position (searching point in the solution space) can be modified by the following equation:

$$S_i^{k+1} = S_i^k + V_i^{k+1} \quad \ldots(12)$$

5.2 Particle Swarm Optimization Algorithm

Flow Chart as shown in Figure 4 is used for MATLAB coding to find the PID controller parameters and function calling of DC motor transfer function is done to find the close loop unit step response.

5.3 Algorithmic Approach for the Specified Design

In our case, we cast the PID controller design problem in PSO framework as given. We consider the three dimensional search space. KP, KI and KD are the three dimensions. We consider the fitness function based on time domain Characteristics for adaptation. We set the number of adaptation iterations based on expected parameters and time of computation.

5.4 Objective Function for Particle swarm optimization

```
function F= tightnes (kd, kp, ki)
T=tf([.023*kd .023*kp .023*ki],[.005 (.010015+.023*kd)
(.000559+.023*kp).023*ki]);
S=stepinfo (T1);
tr=S.RiseTime;
ts=S.SettlingTime;
Mp=S.Overshoot;
Ess=1/(1+dcgain(T1));
F= (1-exp (-0.5))*(Mp+Ess) +exp(-0.5)*(ts-tr);
```

The following table 2 shows the parameters taken for Particle Swarm Optimization Algorithm [8].

Table 2: Parameters of PSO

Parameter	Value
Acceleration Constant C1	1.2
Acceleration Constant C2	1.2
Inertia Weight Factor	0.9
No. of Particles	300
No. of Iterations	50

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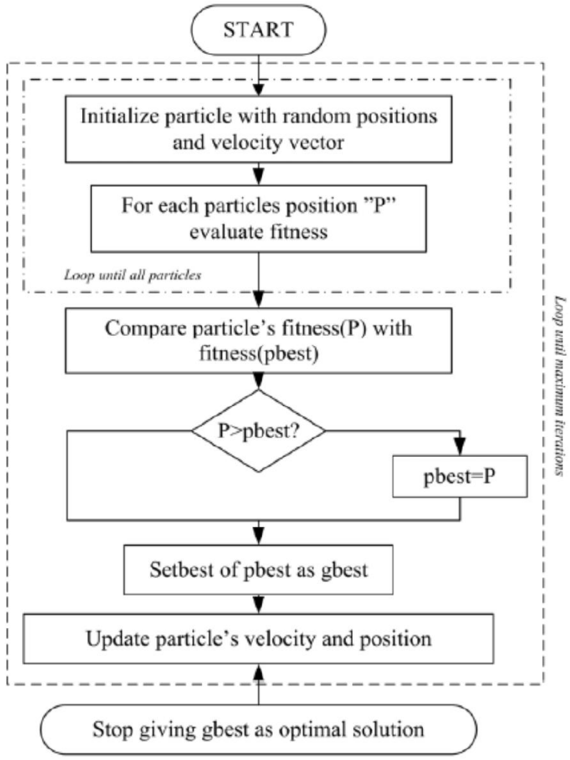

Figure 4: Flow Chart of Particle Swarm Optimization Method

VI. SIMULINK MODEL FOR TUNNING OF PID CONTROLLER TO CONTROL SPEED OF DC MOTOR

The following figure 5 shows that the Simulink Model for Tunning of PID controller to control speed of DC Motor

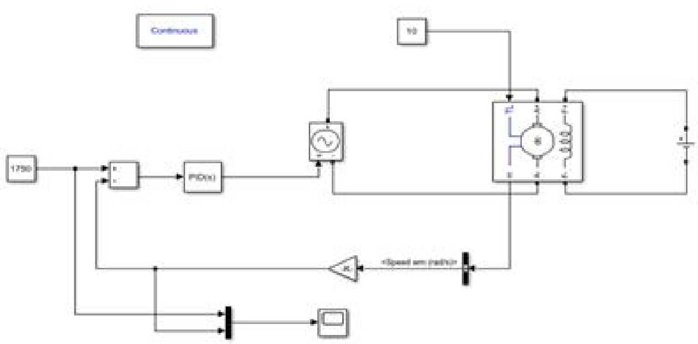

Figure 5: Simulink Model of DC Motor

DOI: 10.48175/568

IJARSCT

ISSN (Online) 2581-9429

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VII. Result and Discussion

The Simulink model in Fig. 5 was simulated and the plots for various tuning method were observed.

Fig. 6 shows the Speed versus Time plot for conventional and bio inspired optimization method (PSO) respectively.

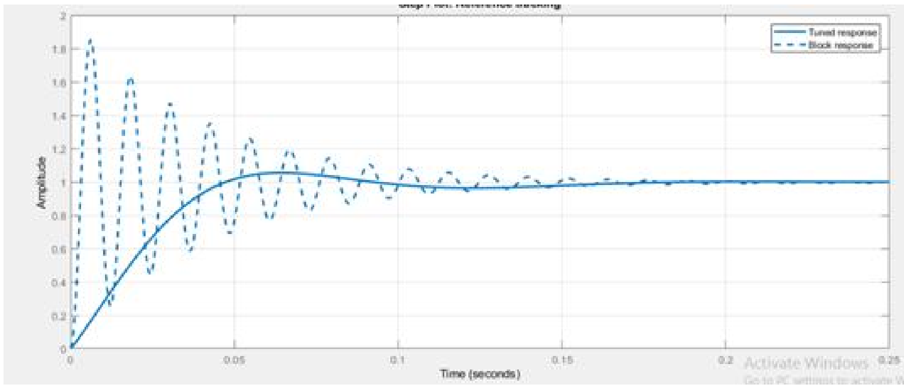

Figure 6: Tunning of PID Controller using PSO and ZN to control speed of DC Motor

From the above result it is clear that bio inspired optimization method is far better than the conventional tuning method. Their comparison is shown in figure 6 and detailed comparative analysis considering all the parameter is given in Table 3.

Table 3: Comparative analysis of ZN and PSO Method

Method	Rise time (sec)	Maximum overshoot (%)	Settling time (sec)
PID-ZN controller	0.00435	85.5%	0.22
PID-PSO controller	0.00209	71.5%	0.171

It can be seen from the above comparison table that while using the bio-inspired technique (Particle Swarm Optimization) the overshoots obtained is 71.5% which is less as compared to the case when the PID Controller is was tuned via conventional methods. The settling time is also lesser in case of the Particle Swarm Optimization, also the rise time is reduced. The Particle Swarm Optimization PID controller tends to approach the reference speed faster and has, comparatively, a zero overshoot. It can be observed from Fig 6 that the Conventional PID controller have overshoot from the reference speed and attain a steady state with larger settling time

VIII. Conclusion

Here we can conclude that from this two method PSO gives the optimum values for all parameters as compared to ZN so that we can control the speed of the DC motor. Compared with traditional ZN method, the proposed method is found indeed more efficient and robust in improving the step response of DC motor drive system.

Acknowledgments

Special Thanks to Professor Dr. Tutkane (Wainganga College of Engineering & Research, Nagpur) for his co-operation.

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