International Journal of Scientific Engineering and Technology Research

www.ijsetr.com

ISSN 2319-8885
Volume.08,
Jan-Dec-2019,
Pages:572-576

Design of Optimal PID Controller for DC Motor Speed Control System with Particle Swarm Optimization Method

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Abstract: The main aims of this research paper is design of optimal PID controller for DC motor speed control system with particle swarm optimization method. There is the model of a DC motor is considered as a second order system for armature voltage control method of speed control. The application of particle swarm optimization, PSO to the PID controller imparts it the ability of tuning itself automatically in an on-line process while the application of optimization algorithm to the PID controller makes it to give an optimum output by searching for the best set of solutions for the PID parameters. Since the optimal PID controller parameters are dependent on the selected weighting factors, the weighting factors was also treated as dynamic optimizing parameters within the Particle Swarm Optimization as a dual optimization and global selection of PID controller optimal parameters as well as best set of weighting factors. In this paper, the bio-inspired optimization technique in controllers and their advantages over conventional methods is discussed using MATLAB/Simulink. Computer simulations and experimental results show that the performance of the optimal PID controller is better than that of the traditional PID controller.

Keywords: PID Controller, Particle Swarm Optimization, PSO, DC Motor, Global Selection, Speed Control.

I. INTRODUCTION

DC motors have long been the primary means of Electrical Traction. DC motor has at torque/speed characteristics compatible with most mechanical loads. The speed control methods of a dc motor are simpler and less expensive than those of A.C Motors and speed control over a large range both below and above rated speed can be easily achieved [1]. DC motor drives are widely used in applications requiring adjustable speed, good speed regulations and frequent starting, braking and reversing. Some important applications are rolling mills, paper mills, mine winders, hoists, machine tools, traction, printing presses, textile mills, excavators and cranes. Fractional horsepower DC motors are widely used as servo motors for positioning and tracking. Although, it is being predicted that AC drives will replace DC drives, however, even today the variable speed applications are dominated by DC drives because of lower cost, reliability and simple control. As per the control of DC motor, there are lot of methods to control the speed and position of the motor. The purpose of a motor speed controller is to take a signal representing the demanded speed and to drive a motor at that speed. PID (proportional-integral-derivative)control is one of the earlier control strategies. It has a simple control structure which was understood by plant operators and which they found relatively easy to tune. Since many control systems using. PID control have proved satisfactory, it still has a wide range of applications in industrial control.

PID control is a control strategy that has been successfully used over many years. Simplicity, robustness, a wide range of applicability and near-optimal performance are some of the reasons that have made PID controller so popular in the academic and industry sectors. Recently, it has been noticed that PID controllers are often poorly tuned and some efforts have been made to systematically resolve this matter. PID control has been an active research topic for many years; since many process plants controlled by PID controllers have similar dynamics it has been found possible to set satisfactory controller parameters from less plant information than a complete mathematical model. These techniques came about because of the desire to adjust controller parameters with a minimum of effort, and also because of the possible difficulty and poor cost benefit of obtaining mathematical models. The PID controller calculation (algorithm) involves three separate parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the 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 adjust the process via a control element. By tuning the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements.

The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Particle swarm optimization (PSO) is an evolutionary meta-heuristic algorithm based on the collective behavior emerging from the interaction of the different search threads that has proved effective in solving combinatorial optimization problems. The PSO was inspired from natural behavior of the bird flock on how they find the optimal path and bring back to their nest by building the unique trail formation. The first algorithm which can be classified within this framework was presented in 1994 and, since then, many diverse variants of the basic principle have been reported in the literature. The objective of this algorithm is to optimize the gains of the PID controller for the given plant. In proposed PSO-PID controller, PSO algorithm is used to optimize the gains and the values are applied into the controller of the plant. The objective of this algorithm is to optimize the gains of the PID controller for the given plant. The proportional gain makes the controller respond to the error while the integral derivative gain help to eliminate steady state error and prevent overshoot respectively.

II. PID CONTROLLER

Generally, PID controllers are composed of three basic control actions (see). They are simple to implement and they provide good performance. The tuning process of the gains of PID controllers can be complex because is iterative: In Equation (1) the first, it is necessary to tune the "Proportional Control" mode, then the "Integral Control", and then add the "Derivative Control" mode to stabilize the overshoot, then add more "Proportional", and so on. The PID controller has the following form in the time domain:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \qquad (1)$$

Where e(t) is the system error (difference between the reference input and the system output), u(t) the control variable, K_p the proportional gain, K_i the integral gain, and K_d is the derivative gain. Each coefficient of the PID controller adds some special characteristics to the output response of the system. Because of this, choosing the right parameters becomes a crucial decision for putting into practice this controller. The effects of these parameters on the output response of the system are shown in Table (1).

Table1.Effects of the Gains in the Response of the System

Gain	Rise Time	Maximum Overshoot	Settling Time	Steady State Error
K_p	Decrease	Increase	Small change	Decrease
K_i	Small change	Decrease	Increase	Small change
K_d	Decrease	Increase	Decrease	Eliminate

PID controller does not "know" the correct output to bring the system to the set point. It moves the output in the direction which should move the process toward the set point and needs to have feedback (measurements) to perform. The main objective function that is selected to be minimized will be considered in this study:

Minimize J, where

$$J = \alpha_1(\text{steady state error}) + \alpha_2(\text{Rise Time}) + \alpha_3\,(\text{Maximum over shoot}) + \alpha_4(\text{settling time}) \qquad (2)$$

Where $\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1$

This objective function J give an operating point which in general is a trade off the four weighted terms of the PID controller depending on the values of weights α_1, α_2, α_3 and α_4 where α_1, α_2, α_3 and α_4 are weighting factors of the four key terms.

III. DC MOTOR MODELING

A DC motor is a useful machine transforming electrical energy to mechanical energy. It is a well-known device and widely used in industrial applications as an actuator. The schematic diagram of an armature-controlled DC motor can be represented in Fig1[4, 5].

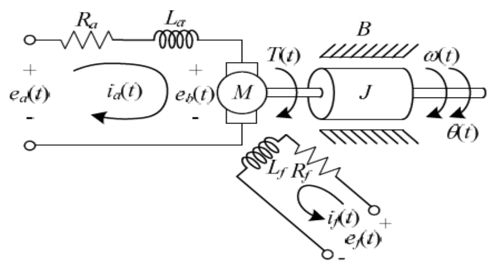


Fig.1. Schematic diagram of DC motor.

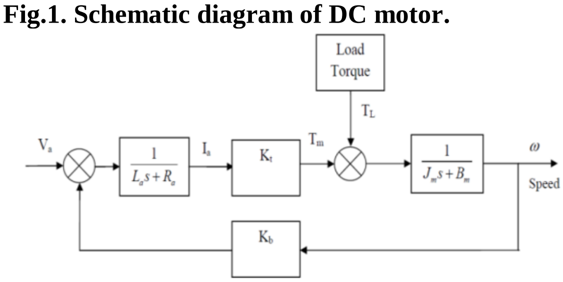


Fig.2. Block diagram of DC motor model.

Once $i_f(t)$ is assumed to be constant, the induced torque T(t), the armature voltage $e_a(t)$ and the back-emf voltage $e_b(t)$ can be expressed in (1), (2) and (3), respectively [4, 8, 10], where K_t is torque constant and K_b is back-emf constant. By taking the Laplace transform of (1), (2) and (3), the s-domain transfer function of a DC motor can be formulated and written as stated in (4).

$$T(t) = K_t i_a(t) = J\frac{d\omega(t)}{dt} + B\omega(t) \qquad (1)$$

$$e_a(t) = R_a i_a(t) + L_a\frac{di_a(t)}{dt} + e_b(t) \qquad (2)$$

$$e_b(t) = K_b\omega(t) \qquad (3)$$

$$\frac{\Omega(s)}{E_a(s)} = \frac{K_t}{JL_a s^3 + (BL_a + JR_a)s + (BR_a + K_t K_b)} \qquad (4)$$

In the state-space form, the equation 3 and 4 above can be expressed by choosing the rotational speed and electric current as the state variables and the voltage as an input. The output is chosen to be the rotational speed.

$$\frac{d}{dt}\begin{bmatrix}\omega_r\\ i_a\end{bmatrix} = \begin{bmatrix}-\frac{B}{J} & \frac{K}{J}\\ -\frac{K}{L_a} & \frac{R_a}{L_a}\end{bmatrix}\begin{bmatrix}\omega_r\\ i_a\end{bmatrix} + \begin{bmatrix}0\\ \frac{1}{L_a}\end{bmatrix}V_a \qquad (5)$$

$$\omega_r = \begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}\omega_r\\ i_a\end{bmatrix} \qquad (6)$$

IV. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is an evolutionary computation optimization technique (a search method based on a natural system) developed by Kennedy and Eberhart [8]-[11]. The system initially has a population of random selective solutions. Each potential solution is called a particle. Each particle is given a random velocity and is flown through the problem space. The particles have memory and each particle keeps track of its previous best position (called the Pbest) and its corresponding fitness. There exist a number of Pbest for the respective particles in the swarm and the particle with greatest fitness is called the global best (Gbest) of the swarm. The basic concept of the PSO technique lies in accelerating each particle towards its Pbest and Gbest locations, with a random weighted acceleration at each time step.

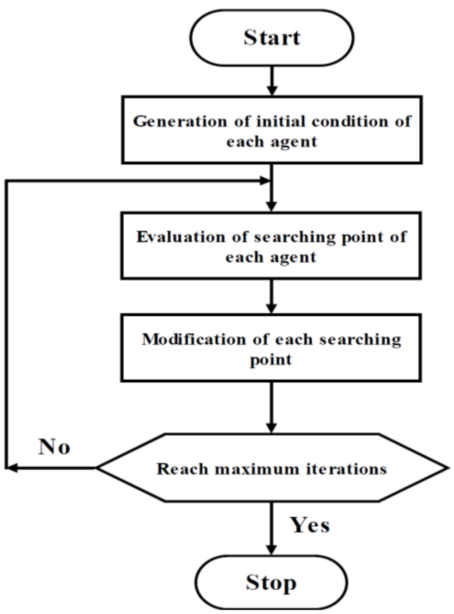


Fig.3. The general flow chart of PSO.

The main steps in the particle swarm optimization and selection process are described as follows:

(a) Initialize a population of particles with random positions and velocities in d dimensions of the problem space and fly them.

(b) Evaluate the fitness of each particle in the swarm.

(c) For every iteration, compare each particle's fitness with its previous best fitness (P_{best}) obtained.If the current value is better than P_{best}, then set P_{best} equal to the current value and the P_{best} location equal to the current location in the d-dimensional space.

(d) Compare P_{best} of particles with each other and update the swarm global best location with the greatest fitness (G_{best}).

(e) Change the velocity and position of the particle According to equations (7) and (8) respectively.

$$\dot{V}_{id} = \omega \times V_{id} + C_1 \times rand_1(P_{id} - X_{id}) + C_2 \times rand_2(P_{id} - X_{id}) \qquad (7)$$

$$X_{id} = X_{id} + V_{id} \qquad (8)$$

Where: V_{id} and X_{id} represent the velocity and position of the i-th particle with d dimensions, respectively. $rand_1$ and $rand_2$ are two uniform random functions, and ω is the inertia weight, which is chosen beforehand.

(f) Repeat steps (a) to (e) until convergence is reached based on some desired single or multiple criteria.

PSO has many parameters and these are described as follows: ω is called the inertia weight that controls the exploration and exploitation of the search space because it dynamically adjusts velocity. V_{max} is the maximum allowable velocity for the particles (i.e. in the case where the velocity of the particle exceeds V_{max}, then it is limited to V_{max}). Thus, resolution and fitness of search depends on V_{max}. If V_{max} is too high, then particles will move beyond a good solution. If V_{max} is too low, particles will be trapped in local minima. The constants C_1 and C_2 in (7) and (8), termed as cognition and social components, respectively. These are the acceleration constants which changes the velocity of a particle towards P_{best} and G_{best} (generally, somewhere between P_{best} and G_{best}). Fig (3) shows the general flow chart of the PSO algorithm.

V. SIMULATION RESULTS

The specifications of the DC motor are given below: Armature circuit Resistance (R_a) 7.56, Armature circuit Inductance (L_a) 0.055 H, Moment of Inertia (J) 0.068 kgm^2, Coefficient of friction (B) 0.03475 N.M.sec/rad, Torque constant (K_t) 3.475 V.Sec/rad, Back-Emf constant (K_b) 3.475 V.sec/rad. The results of minimization using the objective function J are shown in Fig after (50, 100, 150, 200, 250 and 300) repetitive PSO algorithm iterations.

A. Drive response with change in reference speed

The value of K_p, K_d, and K_i corresponding to the best solution obtained is used in the block diagram shown in Fig (4). Even though the design of K_p, K_i, and K_d is carried out assuming that there is no change in reference speed, the values of of K_p, K_i, and K_d obtained through PSO are now used to study the system's response when there is a step change in reference speed as a first track and the second track is assumed as a sinusoidal track. The response of the first speed track (step change) is shown in Fig. (5). Fig (6) shows the system response of the second speed track (sinusoidal speed track).

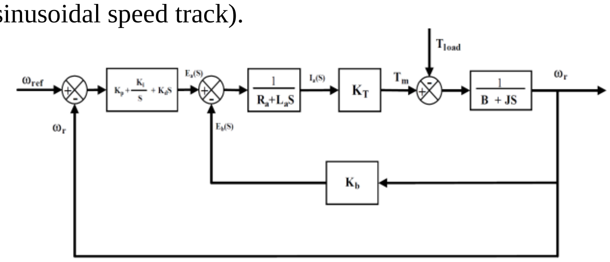
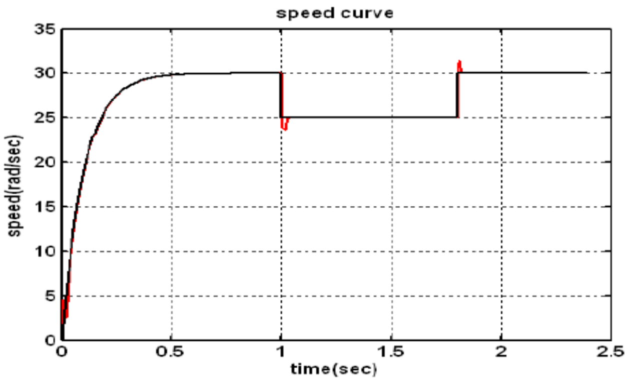
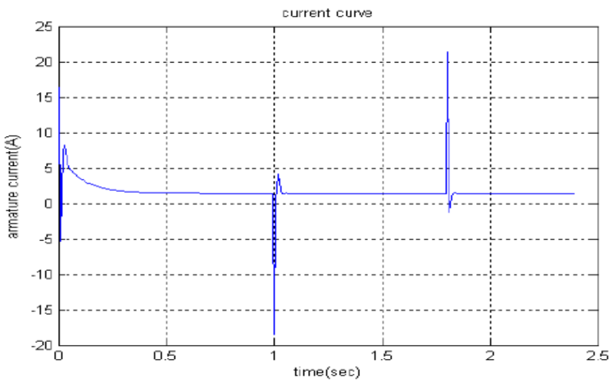


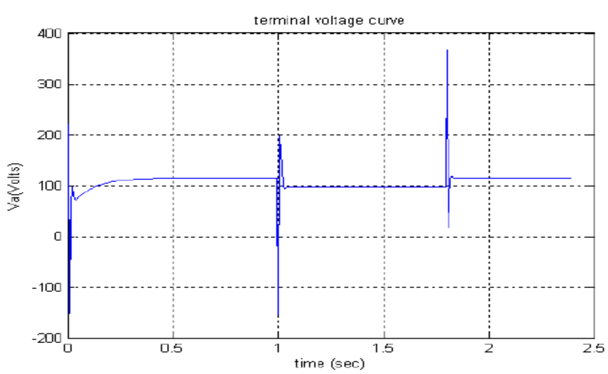
Fig4. Block schematic of PID control system of DC motor drive.



(a)

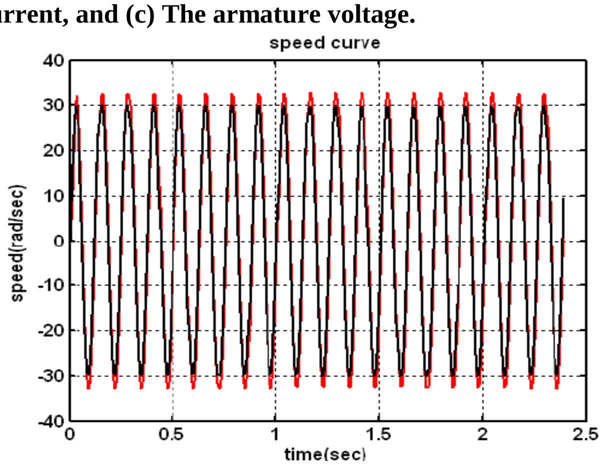


(b)

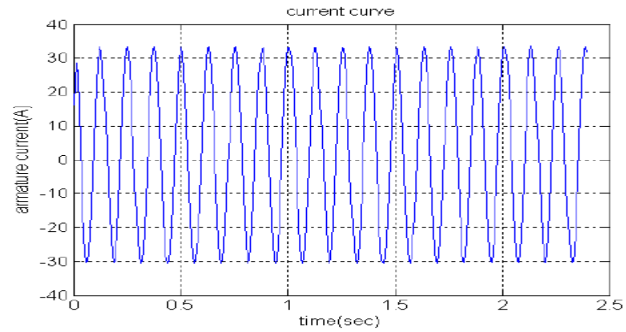


(c)

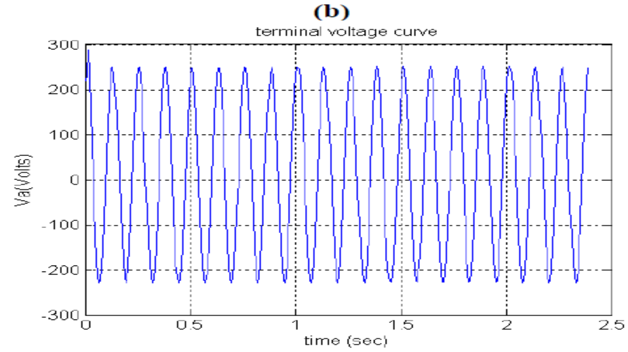
Fig.5. the response of the control system for the first speed track, (a) Speed track response, (b) The armature current, and (c) The armature voltage.



(a)



(b)

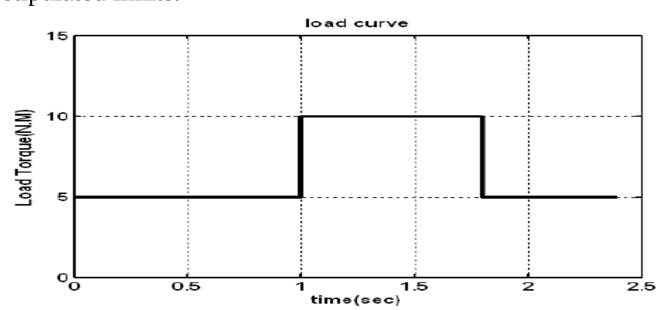


(c)

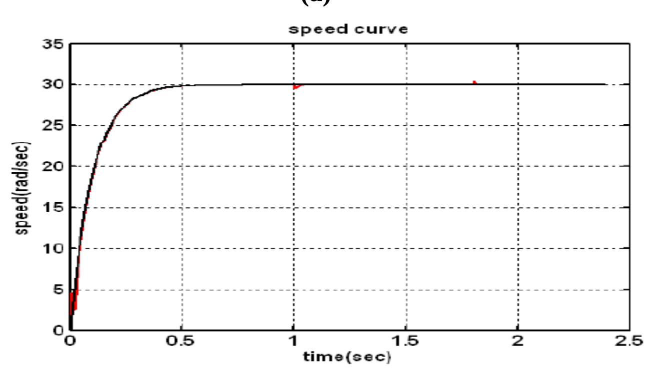
(a) Speed track response,
(b) The armature current, and
(c) The armature voltage.
Fig.6. the response of the control system for the second speed track.

B. Drive response with load change

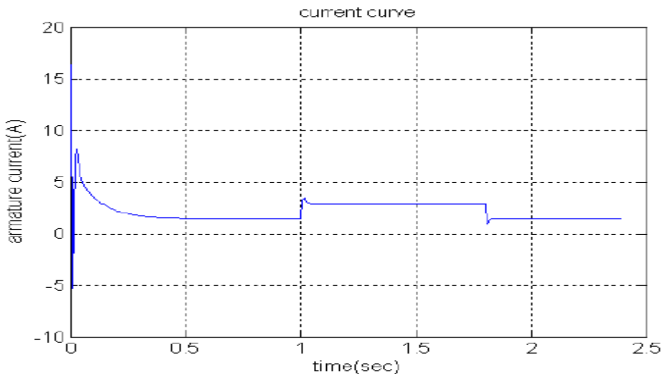
With a step-load disturbance from 5 N-m to 10 N-m, variation of r is shown in the Fig (7) for minimization of objective function J. It can be inferred from this figure that settling time and maximum overshoot is well within the stipulated limits.



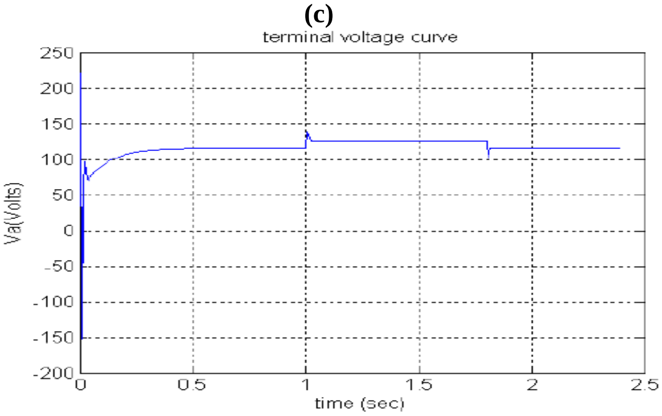
(a)



(b)



(c)



(d)

Fig.7. The response of the control system for the load torque disturbance, (a) Load Torque, (b) Speed track response, (c) The armature current, and (d) The armature voltage.

VI. CONCLUSION

This paper has explained application of Particle Swarm Optimization PSO for the controller design of a separately excited DC motor drive. The main objective functions to be minimized, that will be studied separately, are:

- Minimize the steady state error,
- Minimize the rise time,
- Minimize the maximum overshoot, and
- Minimize the settling time.

The optimal PID controller parameters are dependent on selection of the weighting factors. So the main challenger was to choose these specific weighting factors. The weighting factors as dynamic optimizing parameters within the Particle Swarm Optimization were considered an optimization and global selection of all PID controller and weighting parameters. Since the multiple objectives are converted into a single objective function by aggregating all objectives in a weighted functional, the optimization solution results in a single value that reflects a compromise between all key objectives. This dual optimization PSO process may not be acceptable for systems with multiple conflicting objectives function. So, future work is to use the Discrete Multi-Objective Particle Swarm Optimization (DMOPSO). The Computer simulation results show that an optimized speed response is always obtained with load torque disturbance and change reference speed, as well demonstrate that the excellent performance of the optimal PID controller.

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