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Optimal PID control of a brushless DC motor using PSOtechnique

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Abstract:*This paper proposes PID controller tuning for time delayed process(BLDC Motor) using particle swarm optimization***.** *The Proportional Integral Derivative (PID) structure is mainly used to achieve the desired output in case of closed loop control systems in most of the industry applications. In PID controller it is difficult to obtain the proper values of the controlling parameters Kp, Ki and Kd. The paper describes the design of dynamic control system model with PID controller and the values of the controlling parameters Kp, Ki and Kd are computed by using stochastic global search method i.e. Particle Swarm Optimization (PSO) speed control of a brushless DC motor (BLDC). It is an efficient and fast tuning scheme compare to other conventional techniques. The (BLDC) motor is modeled in simulink in Matlab. The proposed technique was more efficient in improving the step response characteristicsas well as reducing the steady-state error, rise time, settling time and maximum overshoot*.
Keywords: *Partical Swarm Optimisation(PSO), Partical Swarm Intelligence, PID Controller*

I. Introduction

The brushless DC motor (BLDC motor) where the permanent magnet provides the necessary air gap flux instead of the wire-wound field poles.

There are many modern control methodologies such as nonlinear control, optimal control, variable structure control and adaptive control have been widely proposed for speed control of brushless permanent magnet DC motor.However, these approaches are either complex and difficult to implement. PID controller with itsthree terms functionality covering treatment for transientand steady-state response offers the simplest and gets mostefficient solution to many real world control problems. PID (Proportional Integral Derivative) control is one of the earlier control strategies which are used for controlling any plant transfer function. Now to get better efficiency, the actual output should be matched with the set output. Hence some control action should be carried out. Since many control systems using PID controller gives satisfactory result and it helps to tune the control parameters to the optimum values, it is used in industrial control. Now there are various methods to obtain optimum values of the parameters of PID controller for the purpose of tuning. Optimally tuning gains of PIDcontrollers are quite difficult. Recently, the computationalintelligence has proposed Particle Swarm Optimization (PSO) technique for the same purpose.Anew tuning approach "Particle swarm optimization" has been introduced in this paper for tuning of PID controller. PSO was first introduced by Dr. J. Kennedy and R. C. Eberhart in 1995 [X]. Particle swarm optimization is population based technique which is inspired by the social behaviour of biological organism. It is an efficient and fast tuning scheme for solving nonlinear large scale optimization problems.

II. Brushless dc motor

BLDC motor drives, system in which permanent magnet synchronous motor is fed with variable frequency inverter controlled by shaft position sensor. there appears a lack of commercial simulation packages for design of controllers for such BLDC motor drives.

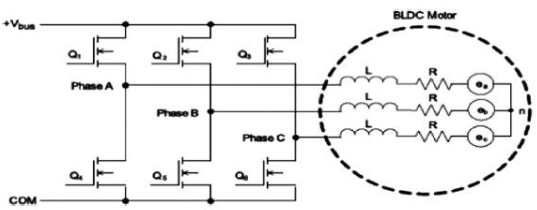

Fig 1. Three-phase full-bridge power circuit for BLDC motor drive.

The BLDC motor is a DC motor turned inside out, so that field is on the rotor and armature is on stator. The brushes DC motor is actually a permanent magnet AC motor whose torque current characteristic mimic the dc motor. Instead of commutating the armature current using brushes, electronic commutation is used. This eliminates the problems associated with the brush and commutatorarrangments. This kind of motor not only has the advantages of DC motor such as better velocity capability and no mechanical commutator but also has the advantages of AC motor such as simple structure, higher reliability and freemaintenance. In addition, brushless DC motor has the following advantages: smaller volume, high torque, and simple system structure. So it is widely applied in areas which needs high performance drive. In this paper a three-phase and two-pole BLDC motor is studied.The characteristic equations of BLDC motor are described by equations (1) (4).

$$V_{app(t)} = L\frac{di(t)}{dt} + Ri(t) + V_{emf} \quad (1)$$

$$V_{emf} = Kb \times \omega(t) \quad (2)$$

$T(t) = Kt \times i(t)$ (3)

$T(t) = J\frac{d\omega(t)}{dt} + D.\omega(t)$ (4)

Where, $V_{app(t)}$ is the applied voltage, ω(t)is the motor speed, L is the inductance of the stator, i(t) is the current of the circuit, R is resistance of the stator, Vemf is the back electromotive force, T is the torque of motor, D is the viscous coefficient, J is the moment of inertia, kt is the motor torque constant, kb is the back electromotive force constant, and Fig.1shows the equivalent circuit of three-phase full-bridge power circuit for (BLDC) motor drive.

III. PID Controller

In Control Engineering, any model is represented by transfer function for single input and single output and linear time invariant dynamical system. The popularity of PID controllers in industry has increased due to their applicability, functional simplicity and reliability in performance. Transfer function of PID controller is shown in Fig.3(a).
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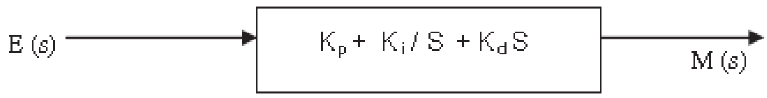

Fig.3(a). Transfer function of PID controller

Where, E(s) is error input signal, M(s) is manipulated output signal. Kp is propotional gain, Ki is integral gain and kd is derivative gain.

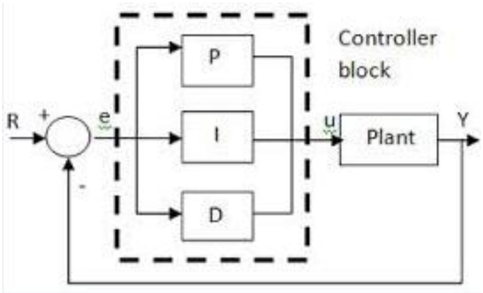

Fig.3(b). Block diagram of PID controller

The optimization methods are introduced for the purpose of tuning the parameters to search for the best solution by minimizing the objective function. To obtain the objective the associated characteristics like rise time, maximum overshoot, settling time, are measured. A set of performance indicators may be used as a design tool to evaluate tuning method.

The parameters Kp, Ki and Kd are chosen to meet prescribed performance criteria, classically specified in terms of rise and settling times, overshoot, and steady-state error. In this paper PSO technique used to find the optimal values of parameters Kp, Ki and Kd of (PID) controller for BLDC motor speed control system.

IV. Overview of Partical swarm optimisation

PSO is an easy & smart artificial techniques and a evolutionary computation technique which is developed by Kennedy &Eberhart [13] .it is used to explore the search space of a given problem to find the settings or parameters required to optimize a particular objective. It is based on following two concepts: (i) The idea of swarm intelligence based on the observation of swarming habits by certain kinds of animals (such as birds and fish), (ii) The field of evolutionary computation .The assumption is basic of PSO. In the proposed PSO method each particle contains three members kp, ki and kd. It means that the search space has three dimensions and particles must fly in a three dimensional space.

PSO is basically developed through simulation of bird flocking in three-dimensional space. The positive of each agent is represented by xyz axes position and also the velocity is expressed by v_x (the velocity of x-axis, v_y (the velocity of y-axis) and v_z (the velocity of z-axis). Modification of the agent position is realized by the position and velocity For n-variables optimization problem a flock of particles are put into the n-dimensional search space with randomly chosen velocities and positions knowing their best values, so far ( ) and the position in the n-dimensional space. The velocity of each particle, adjusted accordingly to its own experience and the other particles flying experience. For example, the ith particle is represented as

Xi=(xi1,xi2,xi3……………..xid) in the d-dimensional space,
the best previous positions of the it□ particle is represented as:
$Pbest$ = ($Pbesti$,1,$Pbesti$,2,$Pbesti$,3………………$Pbesti$,d)
The index of the best particle among the group is Gbest. Velocity of the ith particle is represented as:
Vi = (Vi,1,Vi,2Vi,3………….Vi,d)

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

$$V^{k+1}_i = W \times V^k_i + C_1 rand_1 \times (Pbest_i - X^k_i) + C_2 rand_2 \times (Gbest_i - X^k_i) \quad (5)$$

Where,
V^k_i - Velocity of agent i at iteration k
W - Weighting function
Cj - Correction factor
rand - random no. between 0 and 1
Pbest - particle best position of agent i
Gbest -global particle best position of the group
X^k_i -Current position of agent i at iteration k

The following weighting function is usually utilized in: (6)

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter$$

Where,
Wmax - Final weight
Wmin - Initial weight
iter - Current iteration number
$iter_{max}$ - Maximum iteration number

The current position (searching point in the solution space) can be modified by the following equation:

$$S^{k+1}_i = S^k_i + V^{k+1}_i \quad (7)$$

V. Implementation Of Pso-Pid Controller

5.1 Fitness Function

In This paper a time domain criterion is used for evaluating the PID Controller .A set of good control parameters P,I and D Can yield a good step response that will result in performance criteria minimization in the time domain .These performance criteria in the time domain include the overshoot, rise time, Settling time, and steady state error[4]. Therefore, the performance criterion is defined as follows:

$$W(K) = (1- e-\beta).(Mp + Ess) + e-\beta.(ts - tr) \quad (8)$$

where K is [P,I,D]and β is weightening factor.

The performance criterion W (K) can satisfy the designer requirement using the weightening factor β value. β can set to be larger than 0.5 to reduce the overshoot and steady state error, also can set smaller 0.5 to reduce the rise time and settling time. The optimum selection of β depends on the designer requirement and the characteristics of the plant under control. In BLDC motor speed control system the lower β would lead to moreoptimum responses. In this paper, due to trial, β is set to be 0.5 to optimum the step response of speed control system.
The fitness function is reciprocal of the performance criterion,

$$F = \frac{1}{\omega(k)} \quad (9)$$

5.2. Proposed PID controller

In this paper a PSO-PID controller is used to find the optimal values of BLDC speed control system. Fig.5.2(a) shows the block diagram of optimal PID control for the BLDC motor. In the proposed PSO method each particle contains three members P, I and D. It means that the search space has three dimension and particles must fly in a three dimensional space.

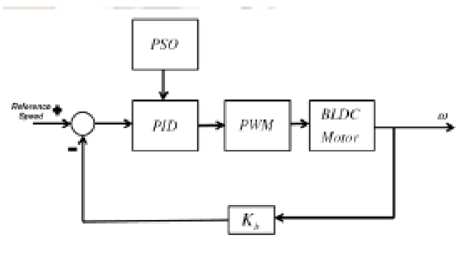

Fig.5.2(a). Block Diagram Optimal PID Control

Flow chart of PSO PID Controller is shown in Fig.5.2(b)

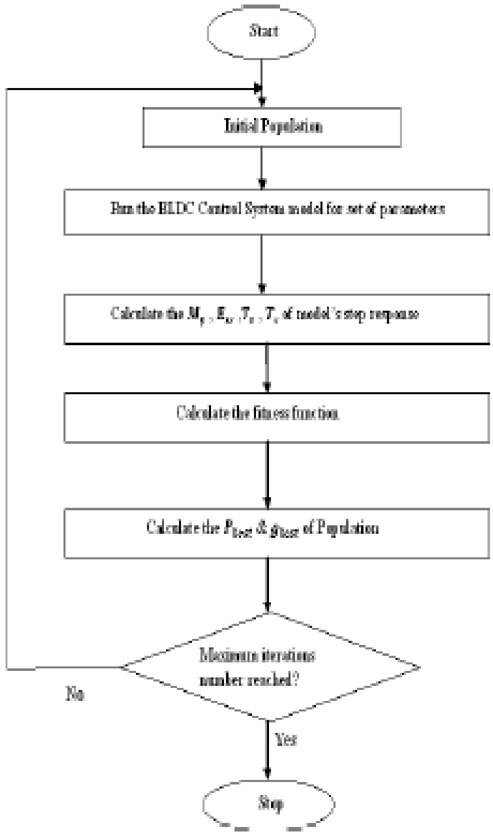

Fig.5.2(b) Flowchart of PID controller

VI. Simulation Results

In this section, a comparison between the proposed and the conventional PID tuning is done. Fig.6(a) shows the error signal for PI,PID controller and PID-PSO approach. Fig.6(b) shows the system output for PI,PID controller and PID-PSO approach. Fig.6(c) shows the control signal for PI,PID controller and PID-PSO approach.Kp_PID=11.327;
Ti_PID=0.0082;
Td_PID=0.00205;
Kp_PSO=6.6397;
Ki_PSO=1;
Kd_PSO=0.0028;

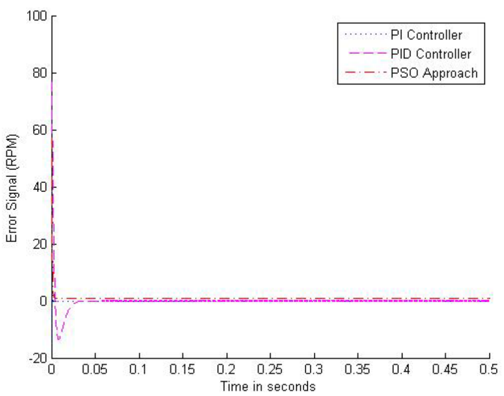

Fig6(a). Characteristic of error signal

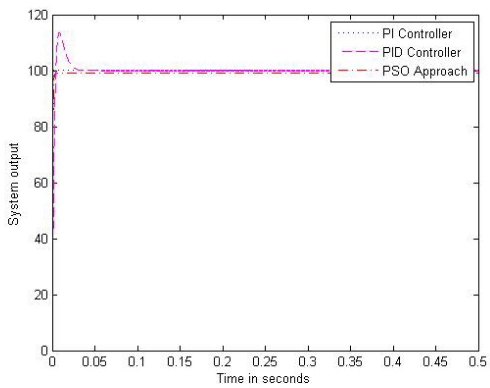

Fig6(b). Characteristic of system output

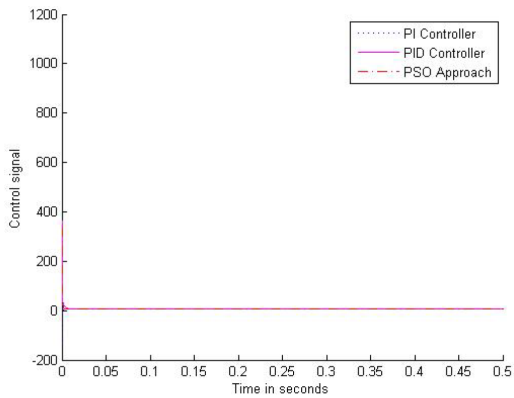

Fig6(c). Characteristic of Control signal

Table 1.PSO(PID) Controller

PSO(PID) Controller	Peak time t_p	Rise time t_r	Settling time t_s	Max. OvershootM_p%	Steady state error e_{ss}
With	0.0035	0.0034	0.0035	0	0.01
Without	0.0065	0.0055	0.0066	0	0.066

VII. Conclusion

This paper presents the application of evolutionary algorithms used as optimization methods for the purpose of parameter estimation of a PID controller rather thanusing classical method of tuning the parameters. The obtained results through the simulation of BLDC motor shows that the proposed controller can perform an efficient search for optimal PID controller and can improve the dynamic performance of the system in a better way.

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