



CHOPPER FED CURRENT CONTROLLED DC MOTOR DRIVE USING PID CONTROLLER WITHOUT SENSOR

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Abstract---This article deals with an interesting application of Proportional Integral Derivative (PID) Controller for speed regulation in a DC Motor Drive. The design of five interdependent controller parameters has been formulated as an optimization problem based on minimization of set point error and controller output. The task of optimization was carried A comparative study has also been made to highlight the advantage of using a PID controller over conventional PID control scheme for speed regulation of application considered. Extensive simulation results are provided to validate the effectiveness of the proposed approach.

KEYWORDS—DC Drive; PID Controller

INTRODUCTION

Although extensive research has been done in designing high performance motor drives, industrial applications are demanding more robust and higher performance drives. To match the criteria of industrial applications, a high performance drive system should maintain dynamic speed command tracking and load regulating response. Among various motor available in the market Direct Current (DC) motor provide excellent control of speed for acceleration and deceleration. The main advantage of using DC motor in drive application is that, power supply is directly fed to field of motor which allows for a precision in voltage control, and which in turns finds useful

in speed and torque control applications. These motors are also capable of providing starting and torques for loads up to 400% than rated. Due to their simplicity, ease of implementation, reliability and low cost, DC motor drives are widely used in industrial applications. They cover wide range of applications including electric traction, golf carts, quarry and mining applications etc. DC motor can be considered as Single Input and Single Output (SISO) system having speed-torque characteristics well-suited with most mechanical loads. This property makes DC motors controllable over wide range of speed by providing good adjustment schemes to terminal voltage. These exemplary features of DC motors made them a good choice for advanced control algorithm and also speed control concept of these motors can be extendable to other types of motor as well. In this application, we considered an armature voltage controlled scheme. Out of various closed loop controller designs available till date, Proportional Integral Derivative (PID) based control scheme is widely preferred in many industrial applications because of their simple structure and ease in realization. Further, PID based speed control scheme has many advantages like less settling time, fast control and low cost. Recent studies revealed a new extension to PID controller with the help of integrations and differentiations based on Fractional Calculus and it is termed as PID controller or PID_{μ} . PID controllers are based on the concept of derivatives (integrals) and recent literature has shown. Voltage obtained will not be in perfect DC form (include few ripples) a

filter with a gain is provided in the feedback path of speed control.

MATHEMATICAL MODEL OF DC MOTOR DRIVE SYSTEM:

In this project, an armature voltage controlled DC motor has been considered. The basic idea of this type of DC motor speed control is that the output speed can be altered by controlling armature voltage for speed below and up to rated speed (under constant field current). To have good speed regulation characteristics, closed loop speed control is preferred

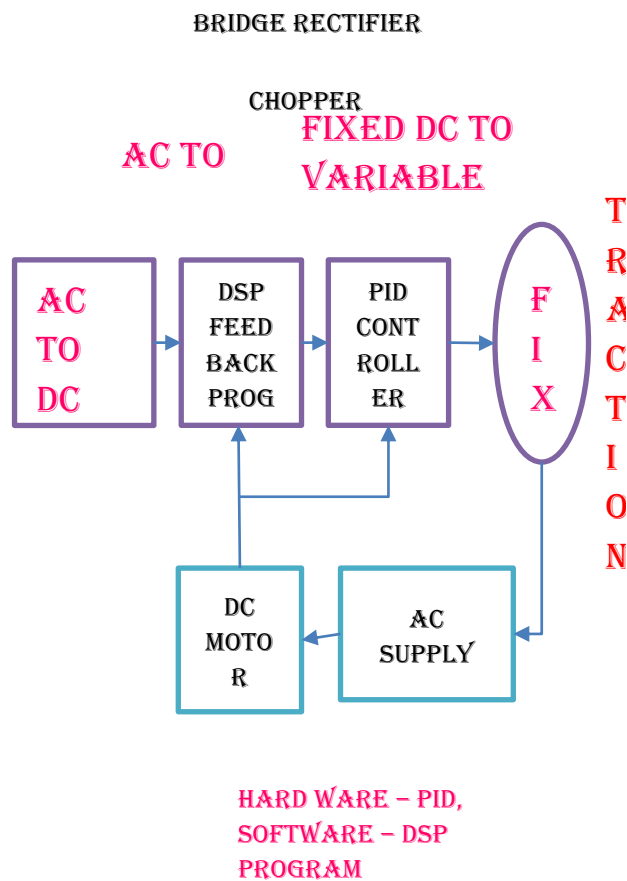


Fig 1.1 Block diagram of Chopper fed DC drives

The basic block diagram for DC motor drive speed control is shown in Figure 1.1. The resultant of reference speed and feedback i.e., error signal is fed as input to speed controller. The output of controller, i.e., control voltage E_c controls the operation of duty cycle of converter.

MODELING OF DC MOTOR

A separately excited DC Motor mainly consists of field winding and armature winding with an independent supply. Field windings are used to excite the flux [2, 8]. A separately excited DC motor is excited by a field current I_f and as a consequence an armature current I_a flows in the circuit. As a result motor develops a back EMF and a torque to balance the load torque at a particular speed level.

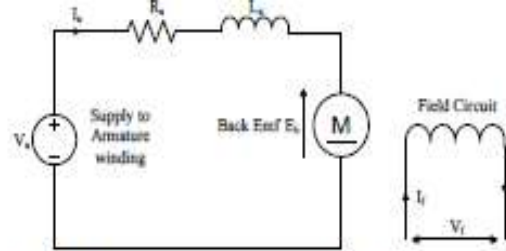


Figure 2. Equivalent Circuit of Separately Excited DC Motor

Applying Kirchhoff's Voltage Law (KVL) to the circuit equivalent in Figure 2 will lead to armature Eqn (1) and the equivalent Torque is given by Eqn (2)

$$V_a = I_a R_a + L_a \frac{dI_a}{dt} + E_b \quad \dots (1)$$

$$T_d = J \frac{d\omega}{dt} + B\omega + T_L \quad \dots (2)$$

Where V_a = armature voltage (Volts); E_b = Motor back Emf (Volts); I_a = armature current (Amps); R_a = armature resistance (Ω); L_a = armature inductance (H); T_L = load torque (N-m); T_d = developed torque (Td); J = Moment of Inertia (Kg/m^2); B = friction coefficient of motor; ω = angular velocity (rad/sec). Assuming negligible friction in motor ($B=0$) Eqn (2) will be reduced to Eqn (3). Further denoting Φ as field flux and K as Back Emf constant, corresponding equations of Back Emf and torque developed can be obtained.

$$T_d = J \frac{d\omega}{dt} + T_L$$

$$E_b = K\Phi\omega \quad \dots (3)$$

$$T_d = K\Phi I_a \quad \dots (4)$$

With the help of above equations and by applying Laplace Transform to Eqn (1) the following equations are obtained.

$$I_a(s) = \frac{V_a - E_b}{sR_a + L_a s} = \frac{V_a - K\Phi\omega}{sR_a + L_a s} \quad \dots (5)$$

$$\omega(s) = \frac{T_d - T_L}{Js} = \frac{K\Phi I_a - T_L}{Js} \quad \dots (6)$$

Where armature Time constant $T_a = L_a/R_a$. The equivalent model of DC motor is shown in Fig 3+. After performing block reduction the

resultant transfer function will be of following form $\omega(s)$

$$V_a(s) = K\Phi / RaJs(1 + sTa)1 + K_2\Phi_2$$

$$Js(1+sTa)=1/K\Phi sTm(1+sTa)+1..... (7)$$

Assuming

$T_m = JRa / (K\phi)^2$ as Electromechanical Time constant. Eqn (7) can be further reduced (replacing $K\Phi$ by K_m and also $T_L = 0$)

$$\omega(s)V_a(s) = 1/K_m(1+sT_m)(1+sT_a).. \quad (8)$$

1. CURRENT CONTROL LOOP

Due to Electromechanical time constant motor will consume some to speed up. On the other hand speed controller used will be acting very fast. Initially speed feedback is zero, and this results in maximum converter voltage V_a . Eventually a large amount of current flow because of zero back EMF. This in course of time may exceed the motor maximum current limit and can damage the motor windings. Hence there is a requirement to control current in motor armature. This problem can be eliminated if closed loop current control scheme can be implemented, in which current controller will take care of motor rated current limit .faster response. Hence by assuming $T_c=T_a$, the equivalent T/F of current controller loop can reduced to following form.

reduced to following form. Speed Control Loop: Figure 3 presents a complete layout of closed loop speed control of DC Motor drive. Based on the drive specifications, controller has to be designed to achieve required speed with in specified constraints. As good control scheme involves analysis of time domain parameters and frequency domain stability, with help of above discussions, Figure 3 can be further simplified to Figure 4. In this approach we considered an also PID controller as speed controller for the DC motor drive.

A reference signal is given as input and the integral of the error obtained is used in tuning the controllers. In this approach a chopper is considered as a converter. It is a static power electronic component, which converts fixed DC input voltage to a variable DC output. Choppers are more efficient as they involve one stage conversion. Chopper works on the principle of pulse width modulation and it involves no time delay in its operation. Hence, it can be represented by a simple constant gain K_t . Detailed explanation of DC-Choppers can be obtained through [9]. As there will be more amount of current flow during starting of motor, design of current controller for extreme condition i.e., for zero back EMF.

OPTIMAL DESIGN OF PID/ PIAD_μ CONTROLLER APID CONTROLLER:

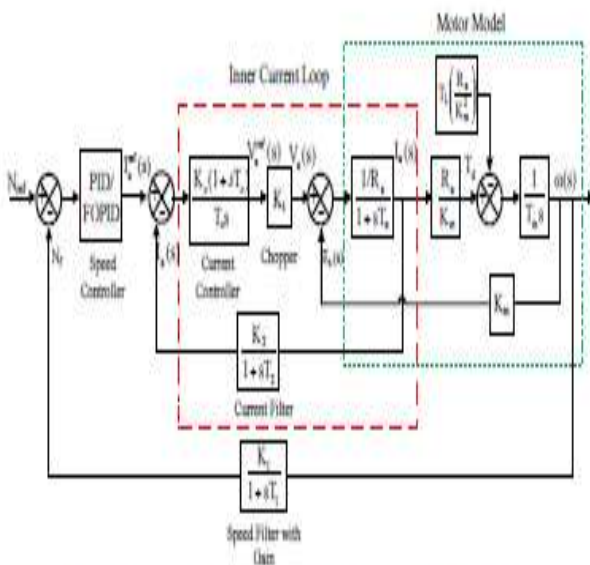


Figure 3. A Complete block diagram representation of Speed Control in a DC Motor Drive

faster response. Hence by assuming $T_c = T_a$, the equivalent T/F of current controller loop can

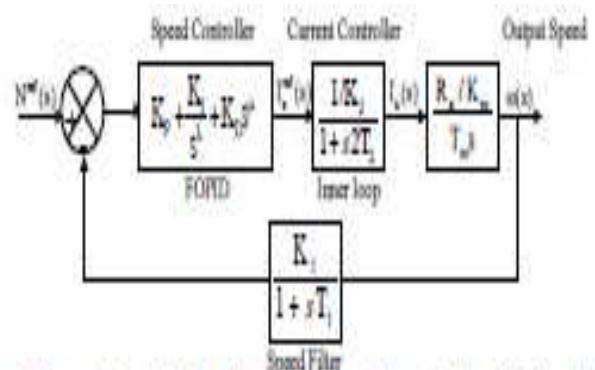


Figure 4. Speed Control of DC Motor Drive: A simplified model

The λ indicates a fractional integral operation. Hence the FOPID controller is a sum of fractional operators along with controller gains. The transfer function representation of a PID controller is given in Eqn

$$C(s) = KP + KIs^\lambda + KDs^\mu$$

This typical controller consists of three controller gains $\{Kp, KI, KD\}$ and two more fractional order operators $\{\lambda, \mu\}$. For Instance, if $\lambda=1$ and $\mu=1$ Eqn *J1* refers to ITSE which tries to minimize the overshoot & settling time. The higher powers in time and error penalizes the output more at later stages and results in very fast rise and settling time. change in set-point this kind of criteria gives very high The idea of a PID or $PI\lambda D\mu$ controller derives its origin from the concept of differentiation and integration. Though popular definitions of fractional derivative like Grunwald-Letnikov and Riemann Loville definitions are prevalent, in terms of fractional order systems Caputo definition is value of controller output, resulting in actuator saturation and integral wind up . To overcome this ITSE is enriched with ISCO term (*J2*), which takes the care of aforementioned problem. The weights $\{w1, w2\}$ balances the impact between control error and control action and both have been chosen to be same for present study (to have same penalt reduces to classical controller in parallel structure. In order to implement a controller of form Eqn(14) Oustaloup's band limited frequency domain rational approximation technique is used in the present paper and also in most of PID control literatures.

4.1 Digital Realization of PID controller:

The rationale behind the choice of frequency domain rational approximation of PID controller is that it can be easily implemented in real hardware using higher order analog or digital filters, corresponding to each fractional order differentiation or This definition of fractional derivative is used to derive fractional order transfer function models integration in PID controller The infinite dimensional nature of fractional order differentiator and integrator in PID controller structure creates hardware implementation issues in industrial application of PID controllers.

However, recent research results demonstrated that band-limited implementation Of PID controllers using higher order rational transfer function approximation of the integro-differential operators give satisfactory performance in industrial applications. Oustaloup's recursive approximation, which has been implemented to realize fractional integro-differential operators in frequency domain, is given by the following equations.

$$s\alpha = Ks + \omega k'$$

$$k = -Ns + \omega kN\Pi$$

Here the poles, zeros and gain of

2. PROBLEM FORMULATION

PID/ $PI\lambda D\mu$ controller parameters are tuned in optimal fashion such that drive gives optimal performance. For tuning of controllers, we considered two objective functions i.e., Integral Time Squared Error (ITSE) criterion and weighted sum of ITSE & Integral Squared Controller output (ISCO) criterion.

In this context $J(X)$ represents either *J1* or *J2* objective functions. Based on above probability relation with respect to food source profitability onlooker tries to exploit a food source making use of Equation and a greedy mechanism similar to employed bee phase is performed. The above two phases i.e., employed bee and onlooker bee phases are performed in round robin fashion. In the due course of iterative process, it may happen that a food source cannot be improved after N number of trials and this ultimately leads to delay in optimization process or leads to poor convergence. To eliminate this, an exploration scheme has been incorporated via scout bee. Each bee will search for a better food source for a certain number of cycles (*limit*), and if the fitness value doesn't improve then that particular bee becomes a Scout. Food source corresponding to that scout bee is abandoned and is initialized to random food source. This process is continued till the termination criterion is reached.

