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Research Article

# Design and Implementation of PID Controller for a two Quadrant Chopper Fed DC Motor Drive

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***Abstract***

*This paper presents the closed loop control of dc motor using chopper with PID controller in first & second Quadrant. The aim of the paper is to explain the design optimization along with low cost implementation of the controller circuit. The design of firing circuit and the controller circuit is done by using low cost components. The parameters of 0.5HP Separately Excited DC Motor are found out and the power circuit is designed using MOSFETs for the motor parameters. First the firing circuit is tested in open loop system to run the motor, and then First Quadrant operation is successfully implemented using closed loop system. The feedback for closed loop system is taken from a dynamo connected to the shaft of the motor. Finally the Two Quadrant operation of Chopper is successfully implemented and got the results by using an optimized low cost firing and controller circuit.*

***Keywords:*** *DC motor, PWM circuit, PID controller, Driver circuit*

## 1. Introduction

For most flexible control a separately-excited DC motor is used, in which the armature and field circuits are provided with separate sources. The speed control in DC motor is widely applied. The speed can be controlled either by the control of armature voltage, field voltage or both depending upon the desired performance characteristics of the drive. As one of possible methods of speed control, effective only with a loaded motor is the armature resistance control (A S Awad *et al*,1997) . This gives the motor a large speed regulation; however, it is generally undesirable because it wastes energy (Dewan S *et al*,1984).

A conventional linear output stage applies a continuous voltage to a load. This can waste plenty of power. On the other hand, PWM applies a pulse train of fixed amplitude and frequency only the width is varied in proportion to an input voltage. The end result is that the average voltage at the load is the same as the input voltage; but with less wasted power in the output stage (Mohammad Tafiqur Rahman *et al*,2009). PWM control works by switching the power supplied to the motor on and off very rapidly. By adjusting the duty cycle of the signal (modulating the width of the pulse, hence the PWM) i.e., the time fraction it is 'on', the average power can be varied and hence the motor speed (H. Sung-Rung *et al*,2004; G. Jovanovic *et al*,2004).

This paper presents to guide the motor speed control with a new technique where the reference signal is feed forwarded to add with error signal (which is the difference between the reference and output signals) and is compared with the triangular wave to generate the train of pulses. The duty cycle of which can be varied to control the speed of the motor.

The structure of this paper is mainly divided in to the mathematical model of DC Motor, DC Motor speed control system, hardware implementation, MATLAB simulation results, and conclusion.

## 2. Mathematical Model of DC Motor

This DC motor system is a separately excited DC motor, which is often used to the speed controlling and the position adjustment. This paper focuses on the study of DC motor linear speed control, therefore, the separately excited DC motor is adopted. Make use of the armature voltage control method to control the DC motor velocity, the armature voltage controls the distinguishing feature of method as the flux fixed, is also a field current fixedly. The control equivalent circuit of the DC motor by the armature voltage control method is shown in Figure 1.

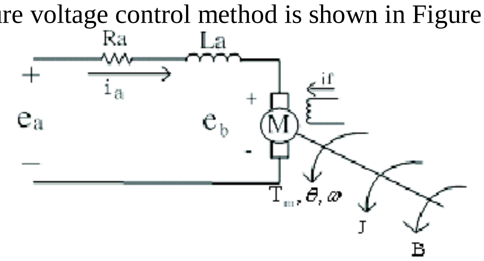


Figure 1: The structure equivalent circuit of the DC motor

Where,

$R_a$ : the armature resistance

$L_a$ : the armature inductance

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$i_a$ : the armature current
$i_f$ : the field current
$e_a$ : the input voltage
$e_b$ : the back electromotive force (EMF)
$T_m$: the motor torque
ω: an angular velocity of rotor
J : rotating inertial measurement of motor bearing
B: a damping coefficient
Because the back EMF $e_b$ is proportional to speed ω directly, then

$$e_b(t) = K_b \frac{d\theta(t)}{dt} = K_b \omega(t) \quad (1)$$

Making use of the KCL voltage law can get

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

From Newton law, the motor torque can obtain

$$T_m(t) = J\frac{d^2\theta(t)}{dt^2} + B\frac{d\theta}{dt} = K_T i_a(t) \quad (3)$$

Take (1), (2) and (3) into Laplace transform, respectively, the equations can be formulated as follows:

$$E_a(s) = (R_a + L_a s)I_a(s) + E_b(s) \quad (4)$$

$$E_b(s) = K_b \Omega(s) \quad (5)$$

$$T_m(s) = B\Omega(s) + Js\Omega(s) = K_T I_a(s) \quad (6)$$

Fig. 2 describes the DC motor armature control system function block diagram from equations (1) to (6).

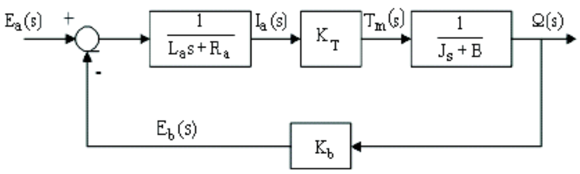



Figure 2: DC motor armature voltage control system function Diagram

The transfer function of DC motor speed with respect to the input voltage can be written as follows,

$$G(s) = \frac{\Omega(s)}{E_a(s)} = \frac{K_T}{(L_a s + R_a)(Js + B) + K_b K_T} \quad (7)$$

From equation (7) the armature inductance is very small in practices; hence, the transfer function of DC motor speed to the input voltage can be simplified as follows,

$$\frac{\Omega(s)}{E_a(s)} = \frac{K_m}{\tau s + 1} \quad (8)$$

Where $K_m = \frac{K_T}{R_a B + K_b K_T}$ is a motor gain,

$\tau = \frac{R_a J}{R_a B + K_b K_T}$ is the motor time constant

From equation (8) the transfer function can be drawn the DC motor system block diagram as shown in the figure (3)

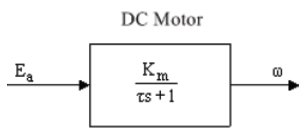



Figure 3: Simplified block diagram of DC motor armature voltage control system DC motor speed control system

## 3. DC Motor Speed Control System

The speed control of DC Motor is implemented using Two Quadrant Chopper circuit shown in fig. 4. To operate the motor in forward direction CH1 is turned ON and diode D1 completes the circuit. To operate the motor in reverse direction CH2 is turned ON and diode D2 completes the circuit.

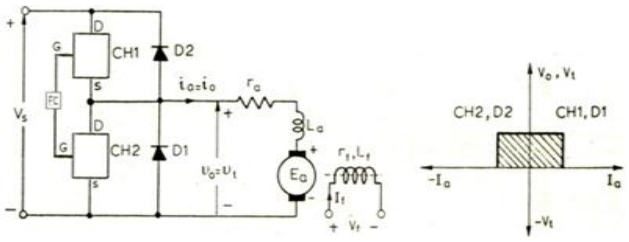



Figure 4: Two Quadrant Chopper Fed Separately Excited DC Motor

The DC Motor speed control system consists of DC Motor, Two Quadrant Chopper, Comparator, PID Controller and a dynamo for feedback.

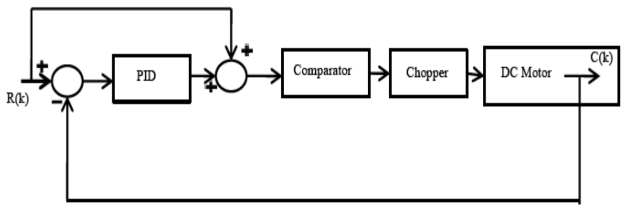
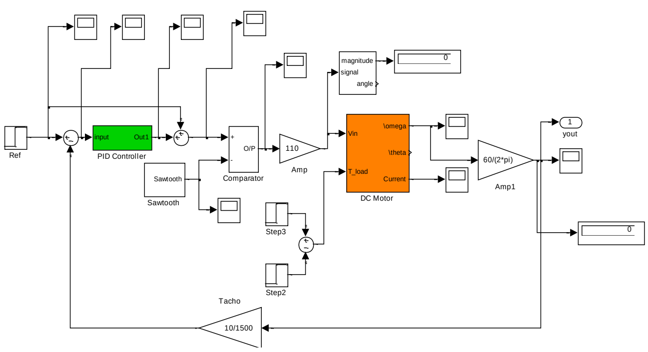
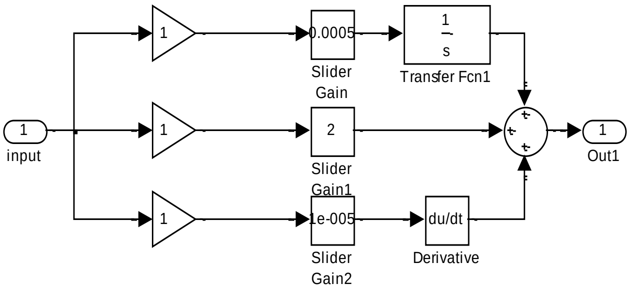



Fig.5. DC motor speed control system

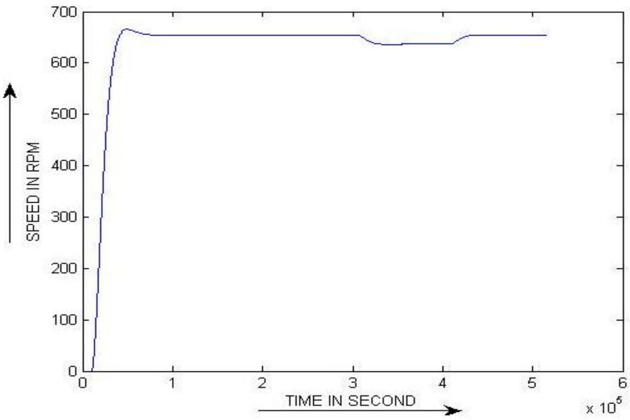
The error signal of the motor speed is introduced to achieve smooth response for different desired signals. To perform this technique, let the output error e(k) be the difference between the desired signal R(k) and the output signal C(k).

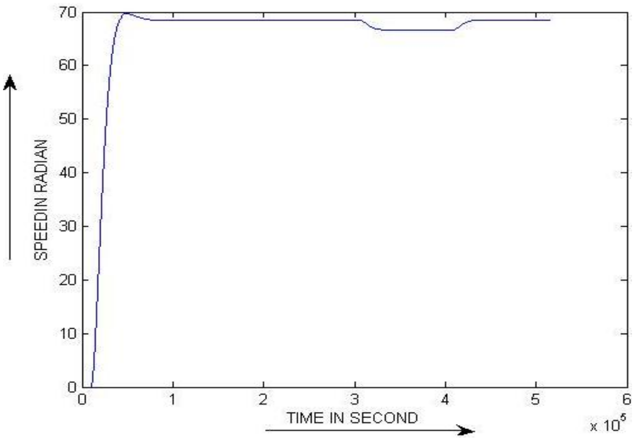
## 4. Matlab simulation

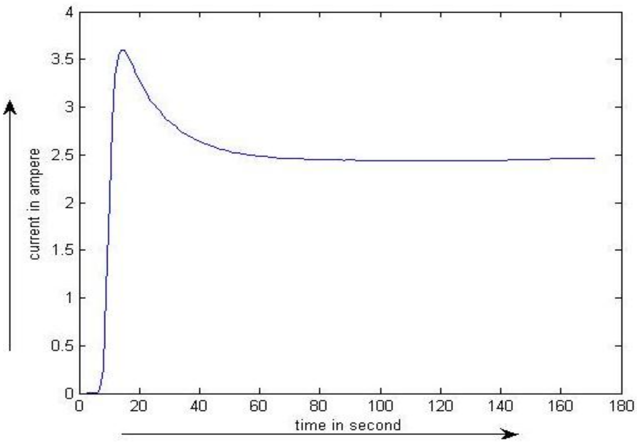


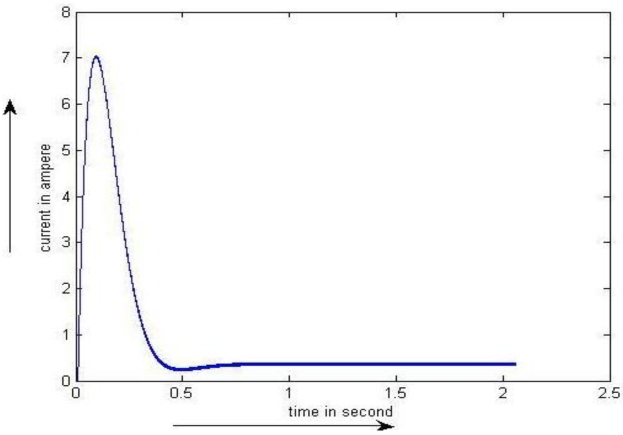



Simulation also consists of PID Block, Comparator and a DC Motor Model. A load torque of 25 N-m is applied at 3 sec and the load is removed at five seconds to verify the operation in open loop system. The speed change is shown in the fig. above. The current control using PID is also been shown in the simulation results.



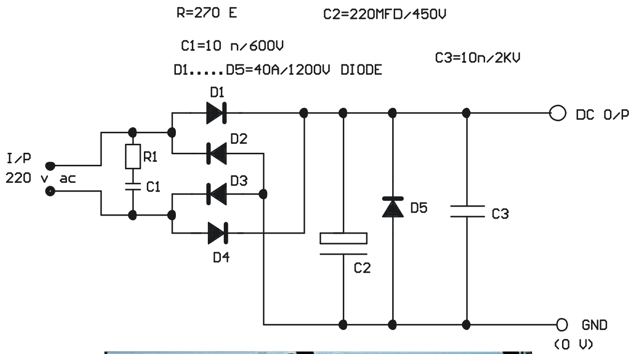




## 5. Hardware Implementation

1) Power Supply:



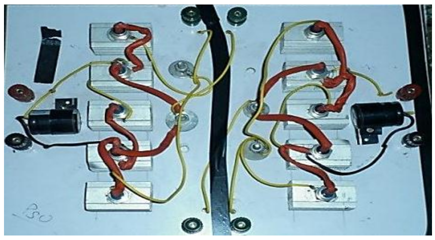



Figure 6: Power Supply

2) Driver Circuit:

The driver circuit consists of Op-Amp, transistors, pulse Transformer, MOSFETs, Resistors, Capacitors and Diodes. The firing circuit will provide pulses to the gate terminal of MOSFET.

The speed of the motor is controlled by controlling the duty ratio of the chopper circuit using a wire wound variable resistance shown in fig. 7.

3) PID Controller:

A Proportional, Integral and Derivative controller is used to implement the closed loop control system for a two quadrant chopper fed DC motor drive. This maintains the speed constant for any load changes. The proportional, Integral and derivative gains are found from the simulation by trial and error method and the values of the components to be implemented are calculated from these results.

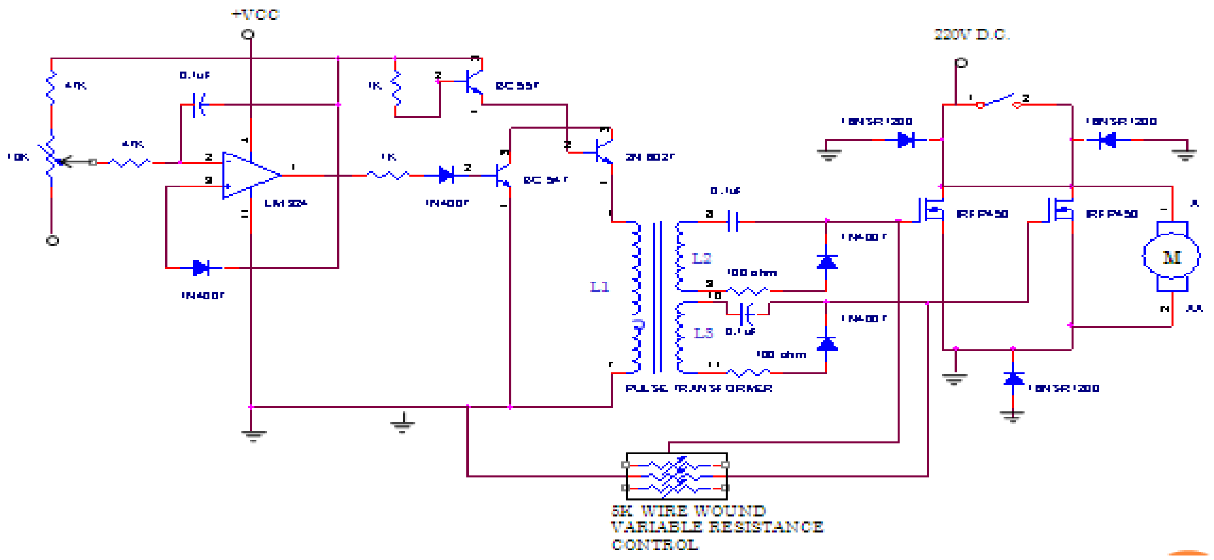
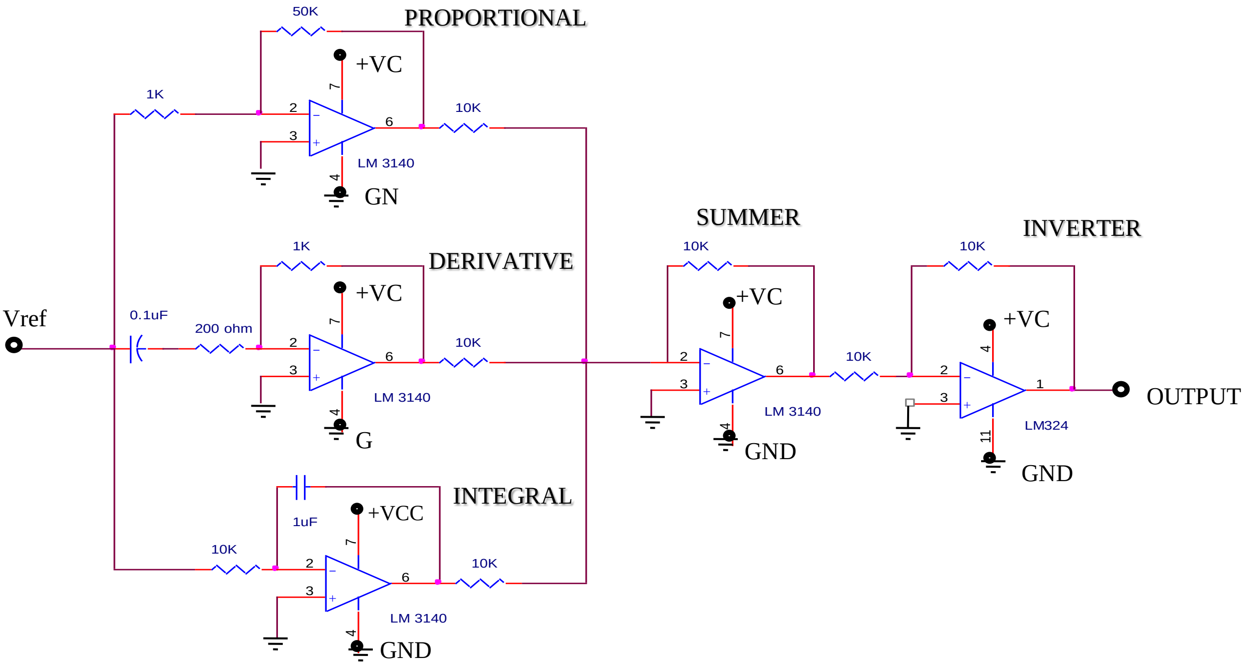



Figure7: Driver Circuit

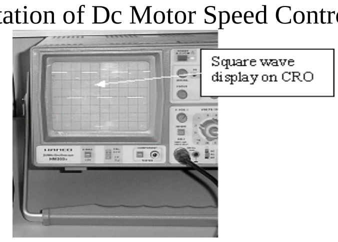



**Integral Gain:** Ensures that under steady state conditions that the motor speed (almost) exactly matches the set point speed. A low gain can make the controller slow to push the speed to the set point but excessive gain can cause hunting around the set point speed. In less extreme cases, it can cause overshoot whereby the speed passes through the set point and then approaches the required speed from the opposite direction. Unfortunately, sufficient gain to quickly achieve the set point speed can cause overshoot and even oscillation but the other terms can be used to damp this out.

**Proportional Gain:** Gives fast response to sudden load changes and can reduce instability caused by high integral gain. This gain is typically many times higher than the integral gain so that relatively small deviations in speed are corrected while the integral gain slowly moves the speed to the setpoint. Like integral gain, when set too high, proportional gain can cause a hard oscillation of a few Hertz in motor speed.

**Derivative Gain:** Can be used to give a very fast response to sudden changes in motor speed. Within simple PID controllers it can be difficult to generate a derivative term in the output that has any significant effect on motor speed. It can be deployed to reduce the rapid speed oscillation caused by high proportional gain. However, in many controllers, it is not used.

4) Implementation of Dc Motor Speed Control System:



## Conclusion

The speed of a dc motor has been successfully controlled by using Chopper as a converter and Proportional-Integral-Derivative type Speed and Current controller based on closed loop system model. Initially a simplified closed loop model for speed control of DC motor is considered and requirement of current controller is studied. Then a generalized modeling of dc motor is done. After that a complete layout of DC drive system is obtained. Then designing of current and speed controller is done. A 0.5HP DC motor specification is taken and corresponding parameters are found out from derived design approach. Ultimately simulation is done for model with and without filter used after reference speed and a comparative study is done on response of both cases. The simulation results under varying reference speed and varying load are also studied and analyzed. The model shows good results under all conditions employed during simulation. By reference with the simulation results hardware is implemented and tested successfully.

## Future Scope

MATLAB simulation for speed control of separately excited DC motor has been done which was implemented in hardware to observe actual feasibility of the approach applied in this paper. This technique can be extended to other types of motors. In this paper, we have done speed control for rated and below rated speed. So the control for above the rated speed can be achieved by controlling field flux. The problem of overshoot can be removed using a Neural Network and Fuzzy approach. It can be further extended to four quadrant chopper controlled drive. The proposed control technique may be used for the speed control of solar power fed DC motor drives which can be used in rural small scale industry application.

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