MIJRD Multidisciplinary International Journal of Research and Development

Multidisciplinary International Journal of Research and Development

Volume: 01 / Issue: 02 / 2021 - Open Access - Website: www.mijrd.com - ISSN: 2583-0406

Performance Enhancement of Chopper Fed DC Motor Speed Control System Using PID Controller

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Abstract— This paper has presented the use of Proportional-Integration-Differentiation (PID) controller to enhance the speed performance of chopper fed direct current (DC) motor. The MATLAB/Simulink model of a chopper circuit and DC motor were developed, and a PID controller was designed and introduced into the system. Simulation was conducted and it was observed that the actual speed has time domain characteristics performance of rise time 0.19 seconds and settling time of 2.50 seconds. The speed of the DC motor was stabilized at 2.50 seconds at a value of 500rad/sec. The results showed that the error signal was maintained at a very small value of 0.01 rad/sec throughout the duration of operation of the DC motor represented by a simulation time of 10 seconds. This means that the controller ensured an effective tracking of the reference speed by the output speed throughout the duration of operation. The armature current performance was rise time of 0.7577 second and settling time of 2.50 seconds with steady current of 10 A. The rise time of the torque is 0.7577 second and settles at 2.50 seconds. The PID controller ensured that the torque operation of the DC motor was maintained at the applied load torque of 10 Nm at 2.50 seconds.

Keywords— Armature current, Chopper circuit, DC motor, PID controller, Torque

I. INTRODUCTION

Direct current (DC) motor is a variable speed drive that is used widely in many industrial applications. The extensive use of DC motor in industry can be attributed to its variable speed characteristics. It can offer starting torque of high magnitude that is required for traction drives, and also capable of achieving large speed range for both below and above the rated speed easily.

Variable speed control method is employed for desired motional operation of the DC motor drives [1]. There are various schemes used in speed control of separately excited DC motor namely, by varying the armature voltage and by varying field flux. The speed control technique often used variable armature voltage control. Thus, varying the speed requires the armature voltage to be varied as well. Semiconductor devices can be used to convert fixed DC voltage to variable DC.

Alternating current (AC) link chopper was used previously for the conversion of constant DC voltage to variable DC voltage. However, this strategy was expensive, bulky and less efficient [1]. In order to address

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this challenge, the DC chopper has been widely used instead. As static power electronic devices involving one stage conversion, DC choppers are more efficient [2] and are being used for rapid transit systems [1, 3]. A DC chopper circuit can use any of the following semiconductor devices: forced commutated thyristor, power bipolar junction transistor (BJT), metallic oxide semiconductor field effect transistor (MOSFET), gate turn-off (GTO) thyristor, and insulated gate bipolar transistor (IGBT).

This paper is designed to simulate and analyse a proportional integral and derivative controller aided chopper fed DC motor speed control system.

II. SYSTEM MODELING

In this section, the various components namely, chopper (switching) circuit and the DC motor, and the controller, of the system are discussed by providing basic operational principle of each item. There after a Simulink model of each item is provided and then a complete circuit diagram developed in MATLAB/Simulink environment that will be used for simulation and evaluation of system performance is presented.

A. Simulink Model of Chopper Circuit

The Simulink model of a chopper circuit utilizing MOSFET for switching or firing operation in DC motor drive speed control designed in this work is shown in Fig. 1. The block parameters of the MOSFET are given Table 1. In this model a capacitor has been added in parallel to the load to eliminate unwanted noise signals before the desired signal is passed to the load (resistance, R). The resistor as a load represents the DC machine.

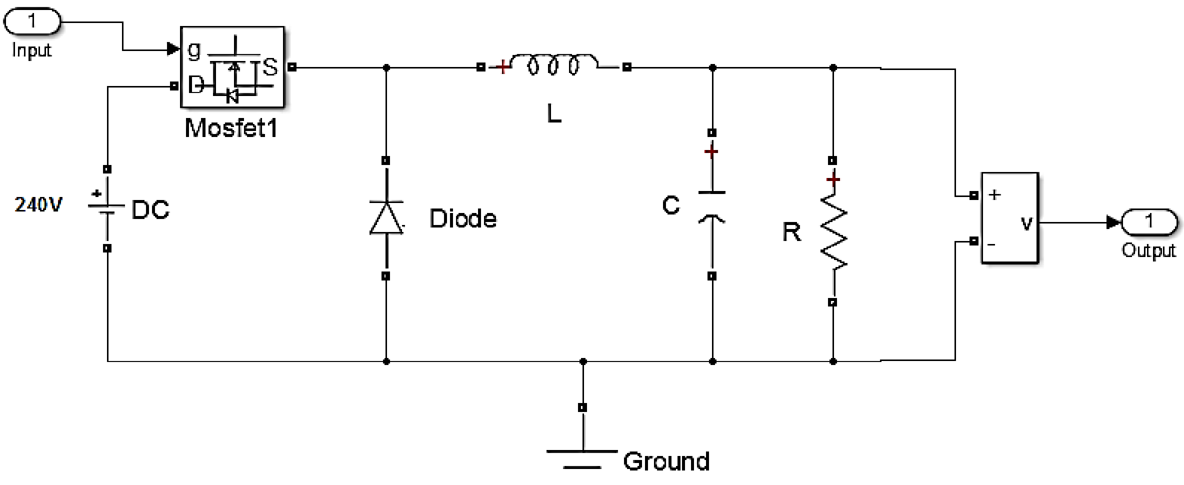

Figure 1: Simulink model of chopper circuit

B. Speed Control Model of DC Motor

This subsection presents the speed control model of DC motor in MATLAB/Simulink. Figure is an electromechanical model of DC motor.

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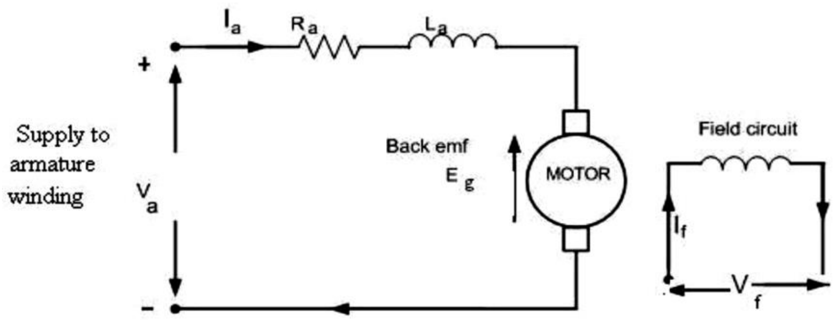

Figure 2: Model of DC motor

The relation of the motor speed with the armature voltage is given by:

$$\omega = \frac{V - i_a R_a}{K\phi} \qquad \text{............ (1)}$$

where ω is the speed in rad/sec, V is the armature voltage, i_a is the armature current, R_a is the armature resistance, K is a constant and ϕ is the flux per pole. Thus it can be seen that it is possible to control the average output voltage and hence the speed by varying the duty cycle. A closed loop circuit with chopper and a proportional integral and derivative (PID) controller designed in MATLAB/Simulink for control a DC motor speed control system is shown in Fig. 3. The block parameter of the DC motor used in Simulink is shown in Table 1.

The set of values of speed at different time intervals (that is the switching or firing time of the chopper circuit using MOSFET as a switching device) is put as input in the lookup table in Fig. 3 whose block diagram parameters is shown in Fig. 4. It can be seen that the lookup table is clocked at time t to generate signal for switch ON and OFF the circuit. The motor speed is fed back to the relational operator through the PID controller which is a closed loop feedback mechanism controller. A PID controller continuously calculates an error value as the difference between a desired set point (Ref. speed) and a measured process variable (Measured Speed).

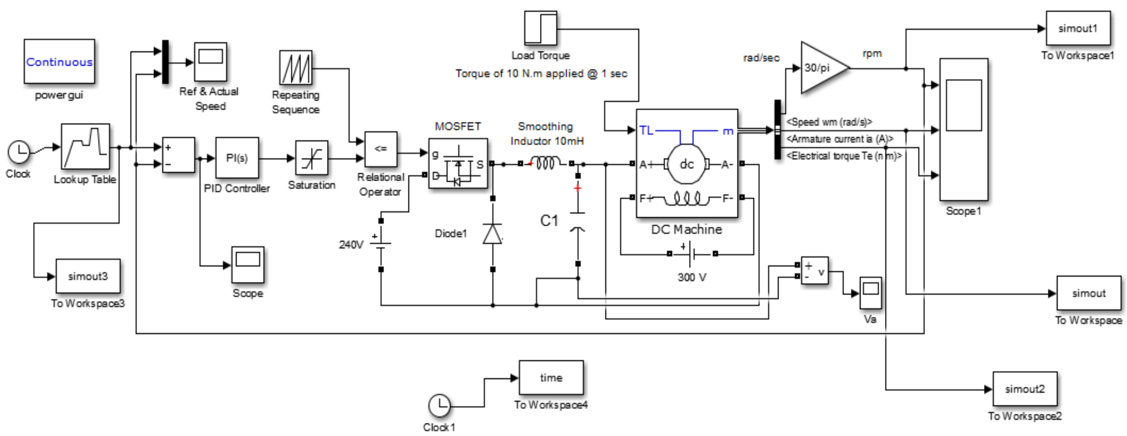

Figure 3: Closed loop speed control of DC motor using chopper

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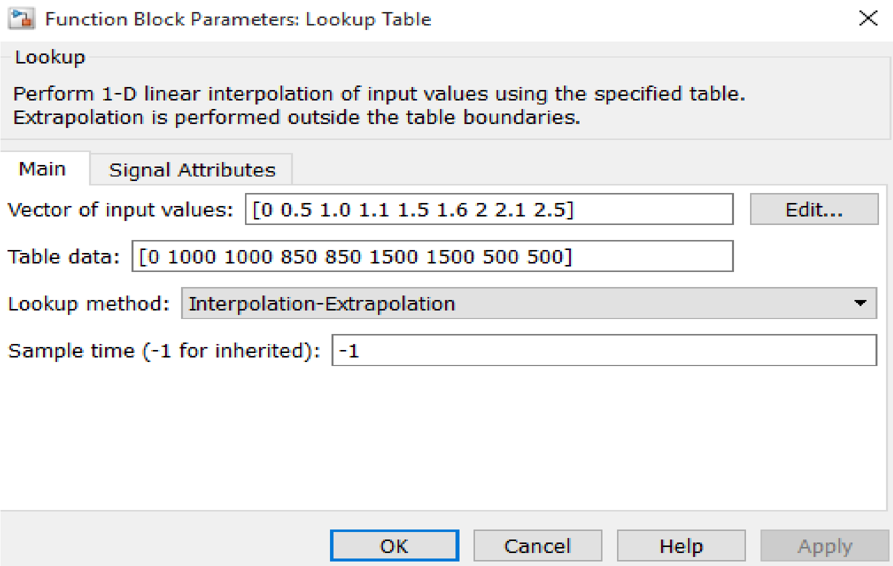

Figure 4: Function block parameters of lookup table (clocked input)

The controller attempts to minimize the error over time by adjustment of a control variable, such as the position of a control valve, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \qquad (2)$$

where K_p, K_i, and K_d, are all non-negative gains of PID controller, denote the coefficients for the proportional (P), integral (I) and derivative (D) terms, respectively (usually denoted as P, I, and D). The values of K_p, K_i and K_d are 0.001, 0.02 and 0.0001. The block diagram of PID controller is shown in Fig. 5.

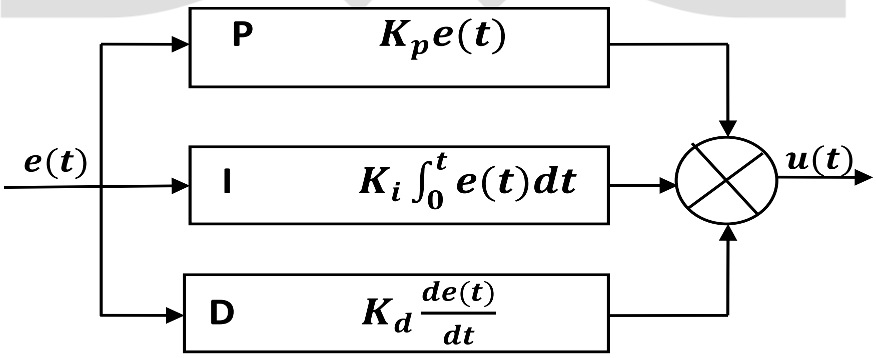

Figure 5: Block diagram model of PID controller

C. Simulation Parameters

The values of the components used for the simulation in this work are given in Table 1.

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Table 1: Simulation parameters

Components	Parameters
MOSFET	FET resistance = 0.1 Ω, internal diode inductance = 0 H, internal diode resistance = 0.01 Ω, internal diode forward biased voltage = 0 V, snubber resistance = 1×10^5 Ω, snubber capacitance = inf
Diode	Resistance = 0.05 Ω, inductance = 0 H, forward voltage = 0.7 V, snubber resistance = inf, snubber capacitance = 0.1×10^{-6} F
Inductance	10×10^{-3} H
Load torque	10 Nm
DC motor	Horse power = 5 hp, supply voltage = 240 V, speed = 1750 rpm, Field voltage = 300 V
Resistance (R)	350 Ω

III. RESULTS AND DISCUSSION

The results of the simulations conducted to evaluate the performance of the designed chopper fed DC motor speed control system are presented. The results are presented in terms of pulse generator profile of the output voltage of the chopper circuit, the actual speed, speed deviation (error), the armature current, and the load torque performance.

A. Result Analysis

The switching voltage of the chopper circuit is a pulse profile which shows the ON and OFF time interval required to control the speed of the DC motor and the simulation plot is shown in Fig. 6. The plot of reference speed and actual (response) speed is shown in Fig. 7. In Fig. 8, the speed deviation representing the error signal fed to the PID control is presented. The deviation is a measure of the difference between the reference (or desired) speed and the actual (response) speed. The plots for the armature current and the torque are shown in Fig. 9 and 10.

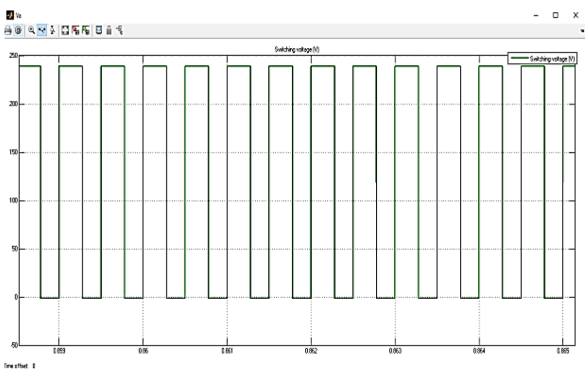

Figure 6: Chopper circuit switch voltage

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Figure 6 shows the response of the chopper as soon as triggering pulse signal is applied to gate of the MOSFET. The signal rises from 0 V (OFF) state to 240 V (ON) state at 0.7742 second.

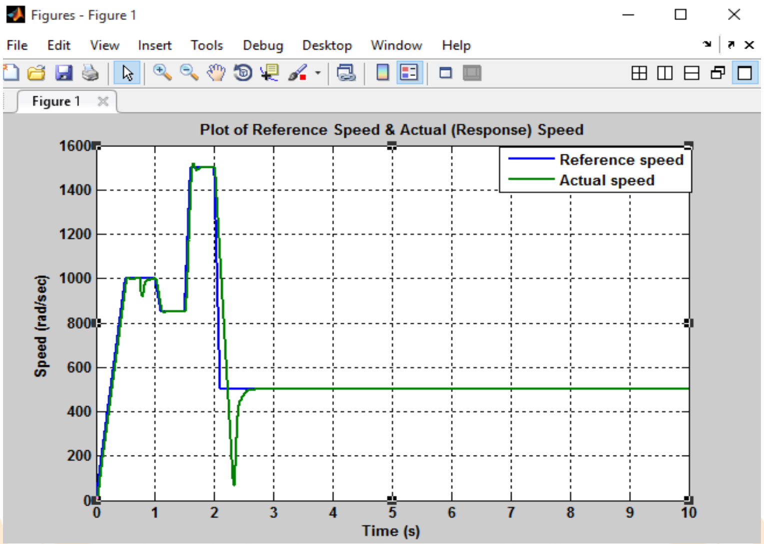

Figure 7: Plot of reference speed and actual speed against time

When the actual or measured motor speed is less than the desired (or reference) speed, the triggering pulse is applied to the gate of the MOSFET. During turn-ON, the MOSFET acts as a closed switch and the armature is fed with supply. In the other case, when the turn-OFF time sets in, the MOSFET acts as an open circuit so as to ensure that the armature is cut off from the supply as shown in Fig. 7. The duty cycle of the chopper circuit presets at 70%. Due to this, the motor speed starts to rise so as to attain the desired speed. When the actual speed is greater than the desired speed, no triggering pulse is fed to the MOSFET gate. Therefore, resulting to the armature cut off from the supply and as such the speed of the motor decreases. This DC motor speed control loop always makes sure that the actual speed of the motor is always close or near the desired speed so as to achieve proper and optimal speed control. Hence, the actual speed has time domain characteristics performance of rise time 0.19 seconds and settling time of 2.50 seconds. The speed of the DC motor was stabilized at 2.50 seconds at a value of 500rad/sec.

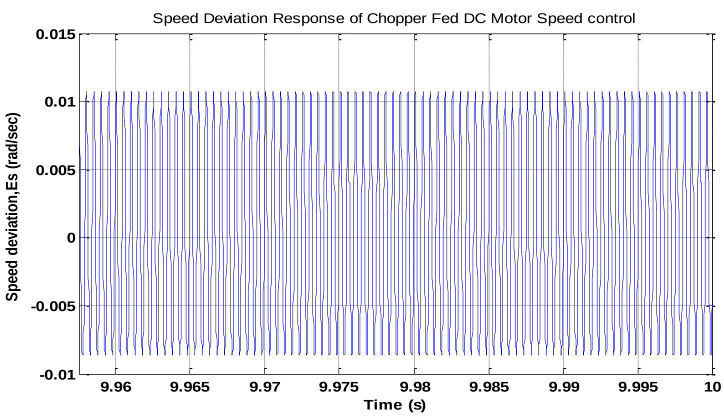

Figure 8: Speed deviation response

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The speed deviation (Es) shown in Fig. 8, also called error signal is the difference between the reference speed and the measured speed. It is quantity that is fed into the PID controller, which manipulates on it and then gives a control variable that ensures that the appropriate triggering pulse is applied to the chopper as to feed the DC motor at the exact time interval. It can be seen that the error signal is maintained at a very small value of 0.01 rad/sec throughout the duration of operation of the DC motor represented by a simulation time of 10 seconds. This means that the controller ensured an effective tracking of the reference speed by the measured speed throughout the duration of operation.

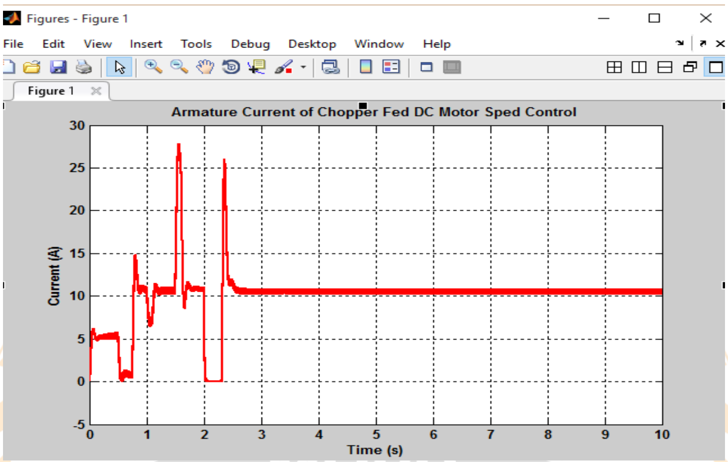

Figure 9: Armature current response

It can be seen in Fig. 9 that as the ON and OFF effect of the pulse signal is fed to the armature circuit, the current rises and falls. This is in accordance with the measured speed of the motor. The current increases during ON state of the pulse signal as long as the measured speed is near or tracked the reference speed. When the measure speed attempts to exceed the reference speed the triggering pulse goes to zero (OFF) and thereby cutting the armature current off the supply which eventually decreases the motor speed. Generally, the time domain performance of the armature current is that it has a rise time of 0.7577 seconds and settling time of 2.50 seconds with steady current of 10 A.

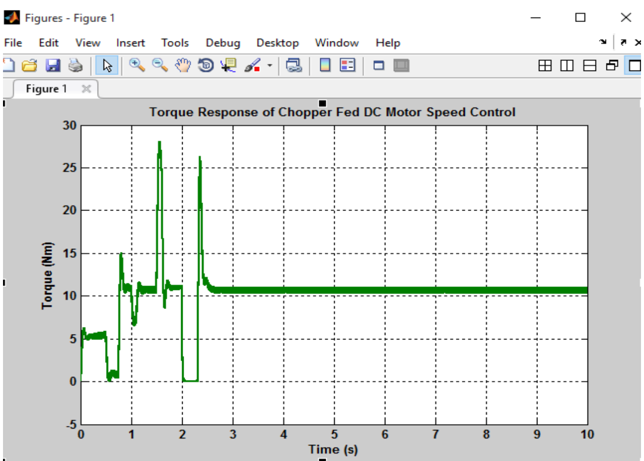

Figure 10: Torque Response

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The performance of the motor torque is in accordance with operation of the armature current as shown in Fig. 10. The rise time of the torque is 0.7577 second and settles at 2.50 seconds. The PID controller ensures that the torque operation of the DC motor is maintained at the applied load torque of 10 Nm at 2.50 seconds.

IV. CONCLUSION

In this paper, the speed of a DC motor has been shown to be successfully controlled by employing a chopper circuit. Initially, the basic output characteristics of a MOSFET based chopper and was studied as well as the output variables for various load characteristics and then move on towards modelling and simulation of a closed loop model of the DC motor system involving the chopper and a PID controller implemented in MATLAB/Simulink. The loops involved are carefully optimized using various mathematical approaches and finally the designed circuit was simulated and the various plots obtained presented. The speed control mechanism of the DC motor system using closed loop control with PID controller has been implemented. The speed control could be further adjusting by changing the pulse width duration being fed to the Gate of the MOSFET which in turn would change the duty cycle and hence would change the armature current.

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