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Chopper Fed Speed Control of DC Motor Using PI Controller

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Abstract : *The speed of the separately excited DC motor can be controlled from below and above the rated speed by using buck converter. This paper presents the speed control methodology by varying armature voltage of the DC motor. The chopper gives variable voltage to the armature of the motor for achieving desired speed using Proportional Integral (PI) controller. The reason behind using PI controller is it removes the delay and provides fast control. The modeling of separately excited DC motor is done and the complete layout of DC drive mechanism is obtained. The reference signal is compared with triangular carrier signal and to produce the PWM pulses for chopper switch. The simulation model is constructed in the MATLAB/SIMULINK. The simulated output parameters of the DC motor such as; armature current, voltage, speed, torque, and field current are analyzed. The results are also verified by constructing an experimental prototype 12V, 24W, DC motor and implementing the Proportional Integral controller in it.*

Keywords: *Armature Voltage control, DC/DC Buck converter, Proportional Integral (PI) controller. PWM generator, separately excited DC motor.*

I. Introduction

Development of high performance motor drives is very essential for industrial applications. A high performance motor drive system must have good dynamic speed command tracking and load regulating response [1]. DC motors provide excellent control of speed for acceleration and deceleration. The power supply of a DC motor connects directly to the field of the motor which allows for precise voltage control, and is necessary for speed and torque control applications [2]. The buck converter is delivers the best performance of the DC-DC step down converter. The power semiconductor devices used for a chopper circuit can be force commutated thyristor, power BJT, MOSFET, IGBT and GTO based chopper are used. It having very low switching losses that means total voltage drop has 0.5V to 2.5V across them [3]-[6].

DC drives, because of their simplicity, ease of application, reliability and favorable cost have long been a backbone of industrial applications. DC drives are less complex as compared to AC drives system. DC drives are normally less expensive for low horse power ratings. DC motors have a long tradition of being used as adjustable speed machines and a wide range of options have evolved for this purpose. Cooling blowers and inlet air flanges provide cooling air for a wide speed range at constant torque. DC regenerative drives are available for applications requiring continuous regeneration for overhauling loads [7]. AC drives with this capability would be more complex and expensive. Properly applied brush and maintenance of commutator is minimal. DC motors are capable of providing starting and accelerating torques in excess of 400% of rated [8]-[9].

DC motors have long been the primary means of electric traction. They are also used for mobile equipment such as golf carts, quarry and mining applications. DC motors are conveniently portable and well fit to special applications, like industrial equipments and machineries that are not easily run from remote power sources [10]. DC motor is considered a Single Input and Single Output (SISO) system having torque/speed characteristics compatible with most mechanical loads. This makes a DC motor controllable over a wide range of speeds by proper adjustment of the terminal voltage. Now days, Induction motors, Brushless DC motors and Synchronous motors have gained widespread use in electric traction system. Even then, there is a persistent effort towards making them behave like DC motors through innovative design and control techniques. Hence DC motors are always a good option for advanced control algorithm because the theory of DC motor speed control is extendable to other types of motors as well. Speed control techniques in separately excited DC motor are by varying the armature voltage for below the rated speed and by varying field flux should to achieve speed above the rated speed [11]-[13].

Different methods for speed control of DC motor are traditionally armature voltage using rheostatic method for low power DC motors, use of conventional PID controllers, neural network controllers, constant power motor field weakening controller based on load-adaptive multi-input, multi-output linearization technique for high speed regimes, single phase uniform PWM AC-DC buck-boost converter with only one switching device used for armature voltage control, using NARMA-L2 (Non-linear Auto-Regressive Moving Average) controller for the constant torque region [14].

Large experiences have been gained in designing trajectory controllers based on self-tuning and PI control. The PI based speed control has many advantages like fast control, low cost and simplified structure. This paper mainly deals with controlling DC motor speed using Chopper as power converter and PI as speed and current controller [10]. Here applying pulse width modulation (PWM) signals to the converter with respect to the motor input voltage it is one of the methods most employed to drive a DC motor. However, the underlying hard switching strategy causes an unsatisfactory dynamic behavior, producing abrupt variations in the voltage and current of the motor [15]. The MATLAB simulation will be used to perform the various conditions of loads but here we are taken as a constant load with small disturbance. So the motor speed will be disturbed with small time period and maintained the constant and PI controller having a different gain value.

II. Dc/Dc Buck Converter

Buck converter is a DC-DC power converter shown in Fig.1. It steps down voltage from its input supply to its output load. It consists of DC input voltage source Vin, controlled switch S, diode D, filter inductor L, filter capacitor C, and load resistance R. The typical voltage and current waveform of buck converter are shown in Fig.2. Under the assumption the inductor current is always positive. It can be seen from the circuit that when the switch S is commanded to the ON state, the diode D is reverse-biased. When the switch S is OFF, the diode conducts to support an uninterrupted current in the inductor [16]-[19].

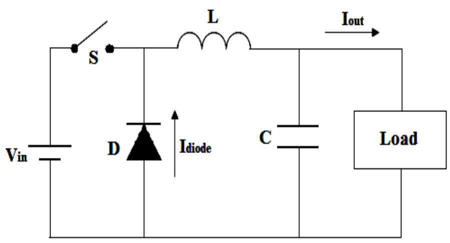

Fig.1. Buck converter

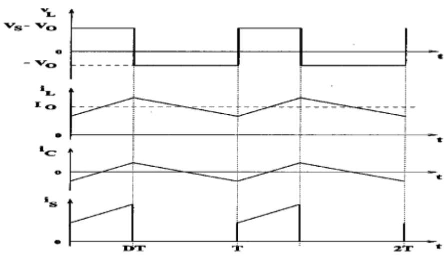

Fig.2. Voltage and current waveform

Fig.2 shows the relationship among the input voltage and output voltage, inductor current I_L, capacitor current I_C, and the switch duty ratio D can be derived, for instance, from the inductor voltage V_L. According to Faraday's law, the inductor volt-second product over a period of steady-state operation is zero [20].For the buck converter, the DC voltage transfer function, defined as the ratio of the output voltage to the input voltage, is

$$\frac{Vo}{Vs} = D \qquad (1)$$

It can be seen from that equation the output voltage is always smaller than that the input voltage. The converter maintains the constant output voltage [21].

III. Circuit Diagram

In that circuit diagram describe the mainly three blocks. They are converter block, motor block and controller block. In that three block connections are given to the Fig.3. Additionally comparator will be used in the block it will compare the actual speed to reference speed and to produced error signal. The main converter circuit it will be produced the fixed DC to variable DC power supply. It will be to given the motor circuitry part. Up to DC motor the part will be consider as the power circuit. Next part of DC motor is measuring work will be done. After the measuring work we are implement the error detection and correction process. At last the circuit diagram will be taken as the feedback control circuit. In each part considering a different work of the speed, current and torque will be controlled.

Here initially given the 240V DC supply on the Vs side. It will connect to the buck converter section. In that buck converter output is given to the armature of the DC motor. Here using separately excited DC motor in that motor field winding are having external DC supply in that range of 300V. DC motor speed will be measured by using on tachogenerator, its output speed is consider the actual speed of the motor. In comparator compare the both actual and reference speed. It produced error signal is fed to the PI controller. In that PI controller rectify the error signal and produced constant signal. PWM generator is comparing the triangular carrier and output signal of the PI controller. At last the output PWM pulse is given to the buck converter as a feedback.

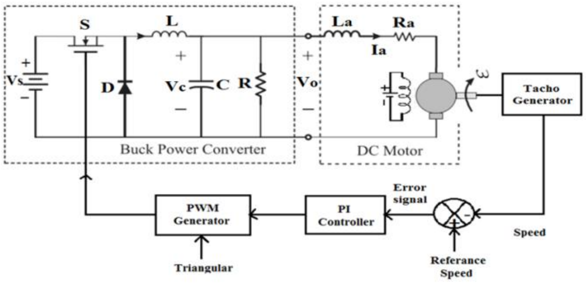

Fig.3. Circuit Diagram

IV. Separately Excited Dc Motor

Fig.4. shows the equivalent circuit of the separately excited DC motor. The separately excited DC motor has armature and field winding with separate supply. The field windings of the DC motor are used to excite the field flux. Current in armature circuit is supplied to the rotor via brush and commutator segment for the mechanical work. The rotor torque is produced by interaction of field flux and armature current.

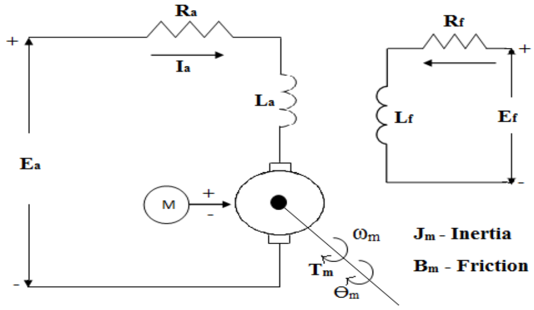

Fig.4. Equivalent circuit of separately excited DC motor

When a separately excited DC motor is excited by a field current of i_f and an armature current of i_a flows in the circuit, the motor develops a back EMF and a torque to balance the load torque at a particular speed. The field current i_f is independent of the armature current i_a. Each winding is supplied separately. Any change in the armature current has no effect on the field current. The i_f is generally much less than the i_a.

V. Pi Controller

The PI controllers are widely used in industrial practice for more than 60 years. The development went the pneumatic through analogue to digital controllers, but the control algorithm is in fact the same. The PI controller is standard and proved solution for the most industrial application. The PI algorithm computes and transmits a controller output signal every sample time (T), to the final control element. PI controllers have two tuning parameters to adjust and the parameters are current I and torque T. PI controller will not increase the speed of response, so it maintain the constant speed of the DC motor. PI controller is mainly used to eliminate the steady state error resulting from P controller. However, in terms of the speed of the response and overall stability of the system, it has a negative impact. This controller is mostly used in areas where speed of the system is not an issue. Since PI controller has no ability to predict the future errors of the system it cannot decrease the rise time and eliminate the oscillations. If applied, any amount of I guarantees set point overshoot. PI controllers are very often used in industry, especially when speed of the response is not an issue.

The PI controller for the current loop using bode analysis or other control system design tools. The next step is usually the design of the speed controller. The 0-db intercept of 1/Js (1+Tis) is normally much too low. The main reason is its relatively simple structure, which can be easily understood and implemented in practice, and that many sophisticated control strategies, such as model predictive control, are based on it. An application with large speed capabilities requires different PI gains than an application which operates at a fixed speed. In addition, industrial equipment that are operating over wide range of speeds, requires different gains at the lower and higher end of the speed range in order to avoid overshoots and oscillations. Generally, tuning the proportional and integral constants for a large speed control process is costly and time consuming. The task is further complicated when incorrect PI constants are entered due the lack of understanding of the process. The control action of a proportional plus integral controller is defined as by following equation:

$$u\,(t) = Kp + Ki \qquad --------(2)$$

Where:

u (t) is actuating signal. e (t) is error signal. Kp is Proportional gain constant. Ki is Integral gain constant.

The Laplace transform of the actuating signal incorporating in proportional plus integral control is

$$U(s) = Kp + Ki \quad ---------- \quad (3)$$

The block diagram of closed loop control system with PI control of DC motor system is shown in Fig.5. The error signal E(s) is fed into two controllers, i.e. Proportional block and Integral block, called PI controller. The output of PI controller, U(s), is fed to DC Motor system. The overall output of DC drive, may be speed or position, C(s) is feedback to reference input R(s). Error signal can be remove by increasing the value of Kp, Ki.

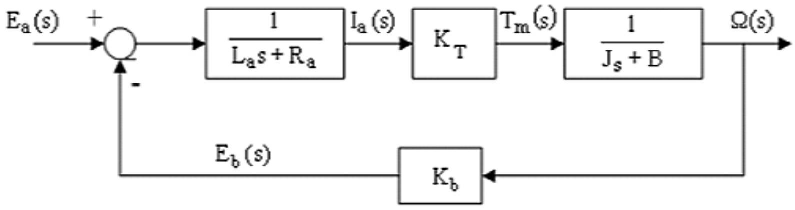

Fig.5 Closed loop control of DC motor

VI. Mat lab Simulation

The MATLAB simulation model is shown in Fig.6. In that model the IGBT is used as a switch for the best performance of speed control, fast switching and low losses. Here 5HP, 240V, 1750 rpm separately excited DC motor and additionally 300V DC supply are given to the field. To take the constant load of the circuit consider its load 20Kg at constantly. In that simulation, there are four motor parameters are monitored by using displays, such as armature voltage, armature current, torque and speed of the DC Motor.

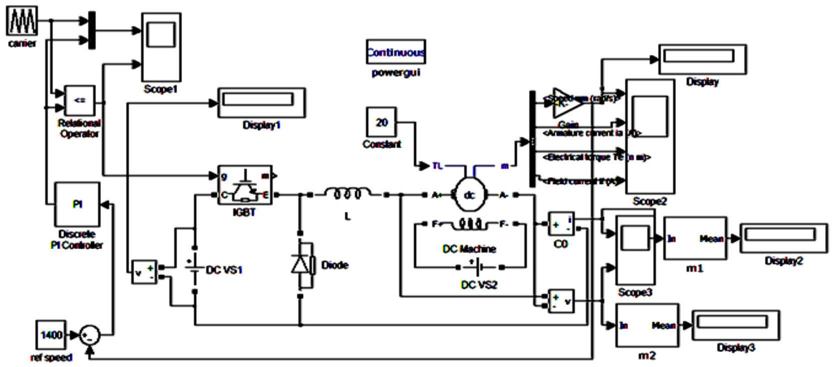

Fig.6. Simulation model of separately excited DC Motor.

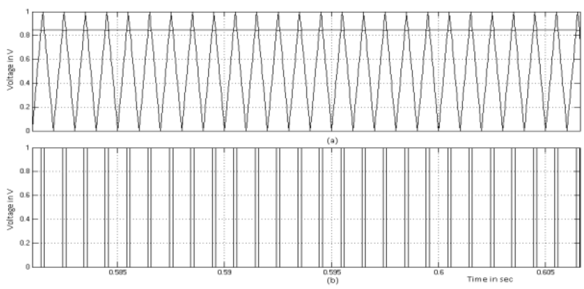

Fig.7.Pulse generation. (a)Triangular carrier and reference signal and (b) PWM Pulses.

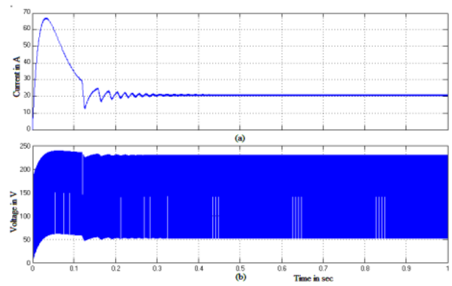

Fig.8. Simulation output of DC motor.
(a) Armature current and
(b) Converter output voltage

Here the freewheeling diode is to maintain continuous current path in the armature. The discrete PI controller gain is chosen by the trial and error method. In that PI controller output is act as the modulation index of the converter. The relational operator can be comparing the reference signal to the carrier signal. To set the maximum reference value of PI controller output is 0.9V. When the carrier signal voltage is more than reference voltage that time IGBT go to OFF or 0 state. Otherwise the IGBT maintain the ON or 1 state. The Fig.7 shows the PWM Pulse generation for the converter. This paper successfully done the simulation for the chopper fed speed control of separately excited DC motor using PI controller. The outputs of the simulation results are show in Fig.8.and Fig .9.

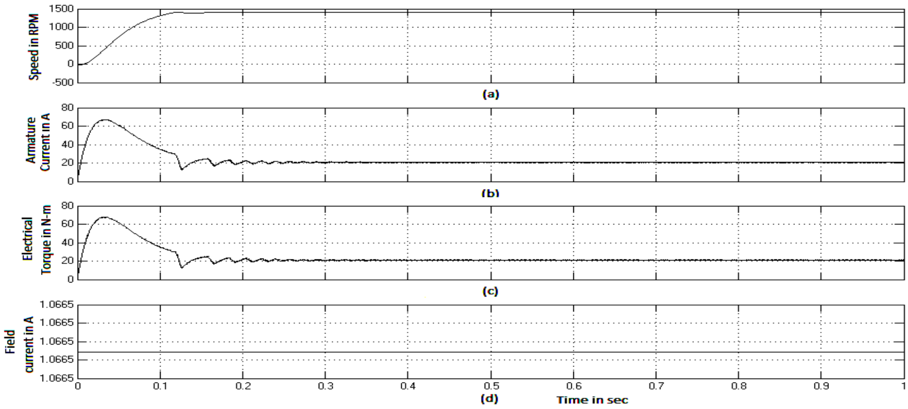

Fig.9. Simulation output of D.C motor. (a)Speed, (b) Armature current, (c) Torque and (d) Field current.

VII. Conclusion

The speed of a DC motor has been successfully controlled by using Chopper as a converter and Proportional Integral as the controller for closed loop speed control system. Initially a simplified closed loop model for speed control of DC motor is considered and requirement of PI controller is studied. Then a generalized modeling of separately excited DC motor is done. The MATLAB/SIMULINK model shows good results under below the rated speed during simulation. The simulation output creates the constant armature voltage and constant field current that time speed and torque of DC motor also produced constant output. Here using buck converters the switching losses will be reduced and motor efficiency are reach approximately more than 95%.

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