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Separately Excited DC Motor Speed Control Using Four Quadrant Chopper

Rishabh Abhinav, Jaya Masand, Piyush Vidyarthi, Gunja Kumari, Neha Gupta

Abstract— The speed of separately excited DC motor can be controlled from below and up to rated speed using chopper as a converter. The chopper firing circuit receives signal from controller and then chopper gives variable voltage to the armature of the motor for achieving desired speed. There are two control loops, one for controlling current and another for speed. The controller used is Proportional-Integral type which removes the delay and provides fast control. Modeling of separately excited DC motor is done. The complete layout of DC drive mechanism is obtained. The designing of current and speed controller is carried out. The optimization of speed controller is done using-modulus hugging approach, in order to get stable and fast control of DC motor. After obtaining the complete model of DC drive system, the model is simulated using MATLAB(SIMULINK).The simulation of DC motor drive is done and analyzed under varying speed and varying load torque conditions like rated speed and load torque, half the rated load torque and speed, step speed and load torque and stair case load torque and speed.

Index Terms— Separately Excited DC Motor, Chopper, PI Controller, IGBT, Armature Voltage Control, Matwork, Simulation, Modulus Hugging Approach

1 INTRODUCTION

DEVELOPMENT of high performance motor drives are very essential for industrial applications. A high performance motor drive system must have good dynamic speed command tracking and load regulating response. A motor speed control is a phenomenon that uses a device or group of devices that serves to govern in some predetermined manner the performance of an electric motor

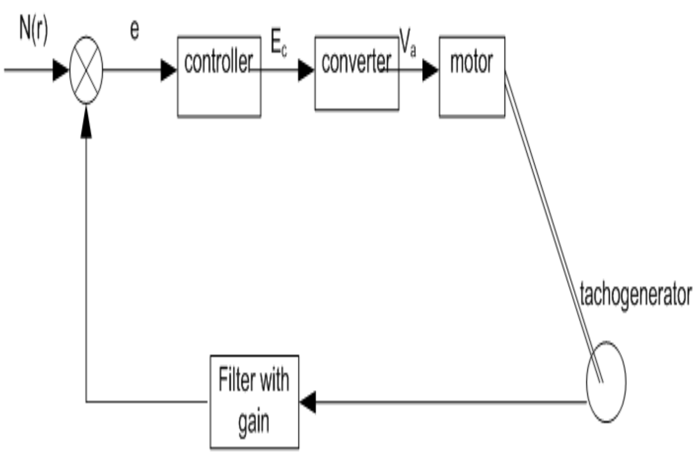
DC motors provide excellent control of speed for acceleration. The power supply of a DC motor connects directly fed to the field of the motor which allows for precise voltage control, and is necessary for speed and torque control applications. DC drives, because of their simplicity, ease of application, reliability and favorable cost have long been 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. DC regenerative drives are available for applications requiring continuous regeneration for overhauling loads. [4]

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. Separately excited DC drives have been used for variable speed applications for many decades and historically was the first choice for speed control applications requiring accurate, speed control, controllable torque, reliability and simplicity. The basic principle of a DC variable speed drive is that the speed of a separately excited DC motor is directly proportional to the voltage applied to the armature of DC motor. The main changes over the years have been concerned with the different methods of generating the variable DC voltage from the 3-phase AC supply. In case of WARD-LEONARD SYSTEM, the output voltage of the DC generator, which is adjusted by controlling the field voltage, is used to control the speed of the DC motor. This type of variable speed drives had good speed and torque characteristics and could achieve a speed range of 25:1. It is no longer commonly used because of high cost of 3 separate rotating machines. In addition, the system requires considerable maintenance to keep the brushes andcommutators of the DC machines in good condition maintenance to keep the brushes and commutators of the DC machines in good condition. [2]

- *Rishabh abhinav is currently an assistant professor in electrical and electronics engineering in Galgotias College Of Engineering &Technology,India ,PH-+918745000401.E-mail :ricks117@gmail.com*
- *Jaya Masand is currently pursuing bachelor's degree program in electrical and electronics engineering in Galgotias College Of Engineering & Technology,India ,PH-+919711723917.E-mail: jayamasand423@gmail.com*
- *Piyush Vidyarthi is currently pursuing bachelor's degree program in electrical and electronics engineering in Galgotias College Of Engineering & Technology,India, PH-+917503806929.E-mail: pvgreenblood@gmail.com*
- *Gunja Kumari,is currently pursuing bachelor's degree program in electrical and electronics engineering in Galgotias College Of Engineering & Technology,India, PH-+918802576929.E-mail: gunjakumari91@gmail.com*
- *Neha Gupta is currently pursuing bachelor's degree program in electrical and electronics engineering in Galgotias College Of Engineering & Technology,India, PH-+91981860725.E-mail: nehagupta1990@gmail.com*

2 PRINCIPLE

Armature voltage control method is used to vary the speed of separately excited DC motor below and upto the base speed. Rated speed is compared with the desired set point speed through a comparator and an error signal is generated. This error signal is fed to a four quadrant chopper using IGBT as switching device. It used as switching device because it has High-current handling capability like BJT, Ease of control of a MOSFET, can withstand High-voltage applications and Operation at high junction temperature is allowed (>100°C).Fixed frequency operation i.e. pulse width modulation technique isused under Time Ratio control.PWM technique isused as the power loss in the switching devices isvery low. When switch is off there is practically no current and when it is on, there is almost no voltage drop across the switch, power loss being the productof voltage and current, in thus both cases close to zero. It also works well with digital control. Now Chopper provides variable voltage across the armature of separately excited DC motor due to which speed of the motor changes.



Principle Used

3 SEPARATELY EXCITED DC MOTOR

Separately excited DC motor has best mechanical characteristics. In past, series motor was used in traction purposes. But due to some limitations like regenerative braking is not possible in DC series motor. In case of DC series motor-field cannot be controlled using static devices. Torque per ampere in low speeds is reduced.

4 EQUATIONS

DC motor: - The armature equation is

◎ $V_a = E_g + I_a R_a + L_a (dI_a/dt)$

◎ $T_d = J d\omega/dt + f\omega + T_L$

◎ $E_g = K \Phi \omega = K_e \omega$

◎ $T_d = K \Phi I_a = K\omega$

◎ (Armature Time Constant) $T_a = L_a / R_a$

◎ (Mechanical Time Constant) $T_m = J/f$

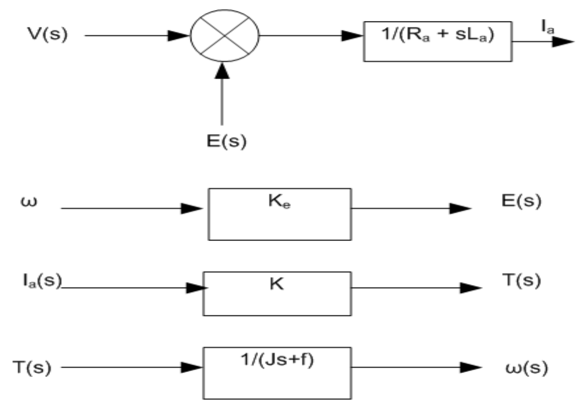
Where,

V_a =Supply Voltage	E_g =Induced emf
I_a =Armature Current	R_a =Armature Resistance
L_a =Armature Inductance	T_d =Torque Developed
J = Moment Of inertia	f = Friction
T_L = Load Torque	Φ = Flux

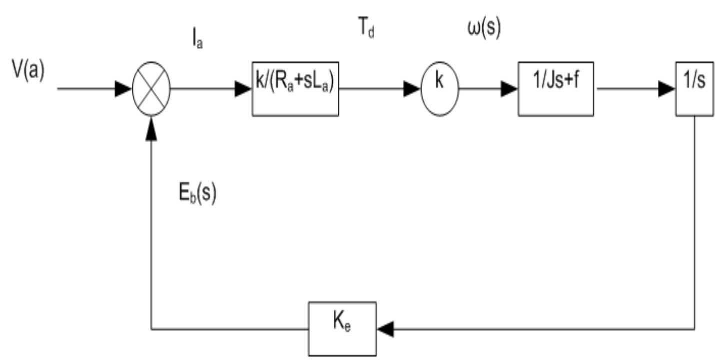
Taking Laplace transform

◎ $V(s)-E(S) = I_a(S)(R_a+sL_a)$

◎ $E(S) = ke\ \omega$



◎ $T(S) = KIa(s)$ [4]

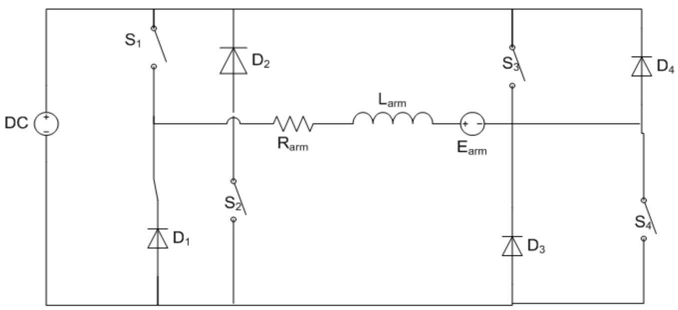


Block Diagram of Separately Excited DC Motor

$$\frac{\omega(s)}{V_a(s)} = \frac{K}{(R_a + sL_a)(Js + f)s + K.K_e}$$

$$\frac{\omega(s)}{V_a(s)} = \frac{K}{R_a s + (1 + sT_a)(1 + sT_m) + K.K_e}$$

5 CHOPPER OPERATION



Four Quarant Chopper

5.1 First Quadrant Operation

Pulses S1 and S4 are given, keeping the S4 on and operating S1. The duty ratio is varied with the help of turning on and off the S1 switch. So when the switch S1 is on, the current takes the path V - S1 - Load -S4 and V. And when S1 if off the current takes the path Load – S4 –D1 and Load. Load current is the sum of the supply current I supply and I sw. The average voltage across the load is positive and the current direction is positive hence this is a 1st Quadrant operation. The output voltage is always less than or same as the supply, hence it is a step down chopper here in the operation. [1]

5.2 Second Quadrant Operation

Only S2 is operated and all the other switches are off, when the S2 is on the current is reversed and the current will flow through Load – S2 – D3 –Load. And when S2 is off, the current will be fed to supply via load – D2 – V - D3-Load. Here the terminal voltage is higher then supply voltage; hence it is a step up chopper. Before that it is necessary that already motor has a Back EMF that allows the current to feedback. [1]

5.3 3rd Quadrant Operation

S2 is on and S3 is operated. Here S1 and S4 are kept off. So when S3 is on, the current takes the path as V –S3 – Load – S2 – V. And when S3 is off the current free wheels through Load - S2- D3 and Load. So here the current is always in same direction and it makes the motor in reverse direction as compared to in the 1st quadrant. The terminal Voltage across the motor and the current flowing through is negative; hence this is the 3rd Quadrant of Operation [1]

5.4 4th Quadrant Operation

Only S3 is operated all the other switches are kept off. Before the motor goes in 4th quadrant, it is necessary that motor should already posses Back EMF so that it can supply back to the source. When S3 is on the current flows through the path Load – D2 – S3 – Load and when the switch S3 is closed the current is fed back to supply via path Load – D2 – V – D3 – Load. Hence over here the current is not changing its direction and stays positive whereas the Voltage across the Motor terminals is becoming negative. Hence we achieve the 4th Quadrant operation. [1]

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7 CONCLUSION

A DC drive system is formed using four quadrant chopper as converter which uses IGBT as its switching device. The drive system works in all four quadrants i.e. in motoring mode in both forward and backward directions. Separately excited DC motor is formulated as a transfer for use in matlab. The simulation of DC drive is analyzed under varying speed and varying load conditions like rated speed and load torque, half the rated load and speed, load torque etc.

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