National University of Singapore

Department of Electrical & Computer Engineering

EE4502: Electric Drives and Control

TUTORIAL - 3 DC Motor Drives

Year 2022-2023

1. A dc separately-excited motor is running at 800 rpm driving a load whose torque is constant. The motor armature current is 500 A. The armature voltage drop and rotational losses are considered negligible. The magnetic circuit can be considered as linear.

   Determine the motor speed and armature current if the terminal voltage is reduced to 50% and the field current is reduced to 80%.

   Repeat the above exercise if the load torque is proportional to the square of the speed.

   (Ans. (a) 500 rpm and 625 A and (b) 500 rpm and 244.14 A)

2. A 250 V, 500 rpm dc separately excited motor has an armature resistance of 0.13 Ω and takes an armature current of 60 A when delivering rated torque at rated flux. The flux is maintained constant throughout the operation.

   (a) Determine the speed at which braking torque equal in magnitude to the full-load torque when regeneratively braking at normal terminal voltage.

   (b) Determine the value of the external braking resistance required to limit the braking current to twice its full-load current at rated speed. Also determine the speed at which braking torque equal in magnitude to the full-load torque is developed.

   (c) Determine the terminal voltage that would be required to run the motor in reverse direction of rotation at rated torque and half rated speed.

   (Ans. (a) 532 rpm, (b) 250 rpm and 1.9 Ω, and (c) -128.9 V)

3. A permanent-magnet DC motor has the following parameters:

$$R_a = 0.5\,\Omega, L_a = 20\,mH, V_{dc} = 500\,V, N_{rated} = 1170\,rpm, I_{a,rated} = 20.0\,A$$

   The DC machine is being driven by a single-quadrant step-down chopper. The chopper frequency is set at 1.0 kHz.

   (a) Determine the chopper duty-cycle for a machine speed of 800 rpm at rated load.

   (b) If the load on the machine is gradually reduced, determine the corresponding electromagnetic torque at which the armature current becomes discontinuous.

   (Ans. (a) 0.69 and (b) 11.3 N.m)

4. A 230 V, 500 rpm, 90 A separately excited dc motor has the armature resistance and inductance of 0.115 Ω and 11 mH respectively. The motor is controlled by a class-C two quadrant chopper operating with a source voltage of 230 V and a frequency of 400 Hz.

   (a) Calculate the motor speed for a motoring operation at $D = 0.5$, and rated torque.

(b) Assume that the motor is operating at a speed on 285 rpm and it is desired to stop the motor as quickly as possible. Derive an expression for the duty-cycle as a function of speed and plot the corresponding variation of motor speed with duty-cycle. Also determine the minimum speed until which regenerative braking at rated torque can be carried out.

(Ans. (a) 238 rpm and (b) 23.7 rpm)

5. A permanent-magnet DC motor has the following parameters:

$$R_a = 0.4\,\Omega, L_a = 1.5\,mH, k_e = 0.5\,V/(rad/s), T_{rated} = 4.0\,N.m, J_m = 0.02\,kg.m^2,$$

The armature is fed from a two-quadrant DC-DC converter. The DC-DC converter is fed from a DC supply voltage of 200 V. The power-semiconductor switches in the DC-DC converter are operated at a switching frequency of 25 kHz.

Calculate, plot and dimension the waveforms of armature voltage, back-emf, armature current and freewheeling diode current for the following operating conditions:

(a) Motoring in the forward direction at a speed of 1500 rpm and supplying a load of 3 N.m.

(b) Regenerative braking in the forward direction at a speed of 1200 rpm and with an armature current of 10 A.

Assume that resistive voltage drop is negligible.

(Ans. (a) D = 0.4, I_a = 6 A and (b) D = 0.289)

6. A permanent-magnet DC motor has an armature resistance of 0.5 Ω. It operates from a 200 V DC supply via a single-quadrant step-down chopper and is required to drive a fan which has a load torque proportional to the square of the speed. The fan requires a torque of 9 N.m, when operating at a speed of 1000 rpm. Assume that $k\phi = 0.6$ N.m/A.

Find the range of the duty-cycle of the chopper necessary for speed control over the range of 200 - 500 rpm.

(Ans. $0.064 < \delta < 0.17$)

7. A 220 V, 1750 rpm separately-excited DC motor is used to drive a pure inertial load at 1500 rpm. The armature circuit resistance is 0.067 Ω. The armature is supplied from a 240 V source by a four-quadrant chopper. The chopping frequency is 400 Hz. The field current is held constant at a value for which $k\phi = 1.28$ N.m/A. It is required to reverse the motor and load as rapidly as possible from this steady-state condition until they are running at 500 rpm in the reverse direction. Motor and load rotational losses may be neglected. The maximum permissible armature current is 290 A.

Assume that the electric circuit variables change the instant a change in their gating signals is made, sketch and dimension the locus of the the operating point on the torque-speed plane.

Sketch and dimension the gating signals for the four-switches in the chopper circuit for (a) constant speed motoring operation at 1500 rpm, (b) immediately after deceleration begins and (c) constant speed reverse motoring operation at 500 rpm.

(Ans. (a) t_{on} = 2.1ms. (b) t_{on} = 1.9ms. and (c) t_{on} = 0.7ms.)

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