Tutorial 2. Controlled converter driven DC motor

PWM converter driven DC motor

1. A separately excited DC motor has the following parameters:

   $V_{a\,rated} = 250$ V, $R_a = 2.5\ \Omega$, $I_{a\,rated} = 20$ A.

   The motor is driven by a 1-Q DC-DC converter (chopper) as indicated in figure 1, which has a switching frequency of 400 Hz. With the rated voltage and rated torque applied, the motor runs at 600 rev/min.

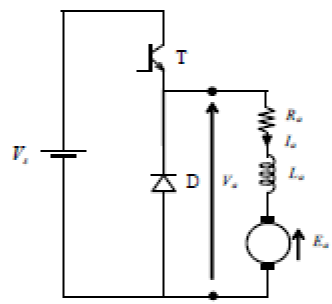

Figure 1. A 1-Q converter

   (i) Calculate the duty cycle D of the converter if the motor speed is to be set at 300 rev/min when (A) the load torque is unchanged and (B) it is reduced by 50%. Assume continuous conduction of armature current in each case. [D = 0.6, and 0.5]

   (ii) Calculate the minimum value of the inductance in the armature circuit if the peak-peak ripple in the armature current is not to exceed 10% of the rated armature current. [L_a = 78 mH]

2. A separately excited DC motor has following parameters:

   $V_{a\,rated} = 260$ V, $I_{a\,rated} = 400$ A, $R_a = 0.0325\ \Omega$, $\omega_{rated} = 1200$ rev/min,

   The motor is driven from a 1-Q PWM DC-DC converter which has a switching frequency of 1 kHz. The lowest speed at which the motor may be driven occurs when the duty cycle of the converter is 0.05. The minimum load at this speed is 10 Nm.

   Find the minimum required value of the armature inductance L_a, so that the armature current will be continuous at all times. [L_a = 0.1625 mH]

3. Consider the drive of question 2. The armature inductance L_a selected for the drive is 0.163 mH. The motor is driven at half the rated speed with a load torque which is half of the rated torque. The load then reduces and motor speed becomes 800 rev/min. Will the armature current be continuous for this condition of operation?

   (i) Calculate the average torque which the motor develops for this condition of operation. [196.15 Nm]

   (ii) Calculate the RMS armature voltage and compare it with the RMS armature voltage had the conduction been continuous. [200V, instead of 184V]

4. A 1-Q PWM DC-DC converter with V_s = 200V drives a separately excited dc motor. The motor armature resistance and inductance are 0.33Ω and 11 mH respectively. With a duty cycle of D = 1, the motor runs at 1200 rev/min when the armature current is 20A. If the speed is to be reduced to 800 rev/min, with the load torque remaining constant, calculate the necessary duty cycle. The converter switching frequency is 500 Hz.

   (i) Is the armature current continuous? [yes]

   (ii) If the armature current is not continuous, calculate the additional armature inductance required to maintain continuous conduction.

5. A separately excited DC motor drives a load that requires armature current of 25 A from a 250VDC supply when driven at 1000 rev/min with rated load. The armature circuit resistance and inductance are 0.7 Ω and 2 mH respectively. A 1-Q PWM DC-DC converter with a switching frequency of 1000 Hz supplies the motor. It is necessary to use the full duty cycle when the top speed of the drive is 1000 rev/min with rated load.

   (i) For what values of load torque and speed will the armature current become discontinuous when the duty cycle $D = 0.5$? [491 rev/min]

   (ii) Find the armature current and the load torque for this condition of operation. [15.57A, 34.57 Nm]

6. A separately excited DC motor is driven from a two quadrant PWM chopper as indicated in figure 2. The two transistors are operated in a bipolar manner at 10 kHz. The motor parameters are:

   $R_a = 1.8\ \Omega$; L_a = 50 mH; K_E = 1 V/rad/sec; $J_m + J_L = 0.22$ kgm²

   The armature rated voltage and current are 200 V and 16 A respectively.

   (i) Calculate the duty cycle D (= $T_{on}/(T_{on} + T_{off})$) of T1 when the motor drives the load at a steady speed of 1250 rev/min at which the total load torque is 15 Nm. [D_{T1} = 0.789]

   (ii) Calculate the peak-peak current ripple (I_{amax} - I_{amin}) for this condition. [0.074A]

   (iii) When the motor is to be slowed down from this speed the duty cycle of T2 must be such that no more than twice the rated motor current flows in the reverse direction. Calculate the required duty cycle for T2 at the start of breaking. [D_{T2} = 0.634]

   (iv) Calculate the duty cycle of T2 when the motor speed has fallen to 750 rev/min if the same peak (-ve) current is maintained as at the beginning of the braking process. [D_{T2}= 0.8705]

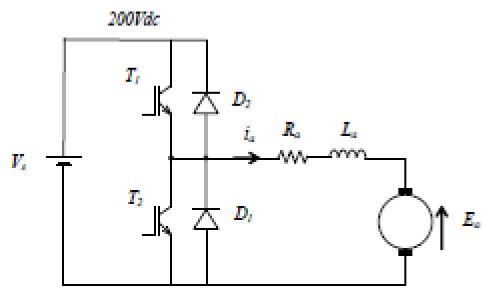

Figure 2. A PWM 2Q converter driven DC motor

Phase controlled converters driven DC motor drive

7. The speed of a 10 hp, 230 V, 1200 rev/min separately excited DC motor is controlled by a single-phase fully-controlled thyristor converter. The rated motor current is 38 A, and the armature resistance is $R_a = 0.3\ \Omega$. The ac supply is 260 V. The motor voltage constant K_E = 0.182 V/rev/min. Assume that sufficient inductance is present in the armature circuit to make the armature current continuous and ripple free.

   For a firing angle of $\alpha = 30^0$ and rated motor current, calculate:

   (a) The motor torque [66 Nm]

   (b) The speed of the motor [1052 rev/min]

   (c) The supply power factor 0.78, lagging]

8. The motor of question 1 is to be braked from the operating condition described above by reversing the armature current using the back emf. This can be arranged by one of three ways: (A) by reversing the armature connection of the motor, (B) by reversing the field connection or (C) by using a separate anti parallel connected converter. For this mode of operation, calculate the firing angle at the instant when braking starts so that the motor armature current is (i) at the rated value (ii) at twice the rated value. Calculate the power fed back to the ac supply in both cases.

   [(A) $\alpha = 140.23°$, P = 6839.62 W
   (B) $\alpha = 136°$, P = 12,812 W]

9. Repeat problem 7 for a half-controlled converter.

   [(a) 66 Nm, (b)1138 rev/min, (c) 0.92 lagging]

10. A 220 V, 1200 rev/min, 150 A separately excited DC motor is considered for a traction drive for which load inertia is large and start/stop duty is frequent. It implies that regenerative braking is desirable. A single-phase, 240V, 50 Hz supply is available. The motor armature resistance, R_a, is = $0.3\ \Omega$. The inductance in the armature circuit is such that the armature

current can be assumed to be continuous at any speed if the load torque is more than 25% of the rated value.

(a) Comment on the suitability of half-controlled VS fully-controlled thyristor bridge converter circuits for the drive.

[Half-controlled converter will not offer regenerative braking]

(b) The motor is required to develop its full rated torque at 1000 rev/min. If a fully-controlled thyristor bridge converter is used, calculate the firing angle for this condition of operation.

[28°]

(c) Calculate the firing angle for this converter if a braking torque equal to twice the rated torque is to be applied when braking is initiated at 1200 rev/min.

[113°]

(*d*) The motor is connected to a load through a 10:1 reduction gear-box. The total system inertia and viscous friction referred to the motor shaft are 1.5 kgm^2 and 0.1 Nm/rad/sec respectively. The minimum load torque is 375 Nm. Calculate the maximum possible deceleration of the load.

[$\alpha_{L,max}$ = −31.2 rad/sec^2]

(e) The motor runs a load at a speed of 450 rev/min when the firing angle is set to 60°. Calculate the developed torque T_m. Is the armature current continuous or discontinuous for this condition of operation?

[197.15 Nm, Continuous]

(f) When the load is reduced from the condition of (*v*), the motor speed rises to 900 rev/min. The firing angle is not altered. Determine whether the armature current will be continuous or discontinuous at this condition of operation.

[Discontinuous]

11. A separately excited DC motor is rated at 500 W, 1000 rev/min, and has armature circuit parameters R_a = 0.15 Ω and L_a = 2.5 mH. The motor is supplied from a single-phase fully controlled thyristor bridge converter which is powered from an ideal single-phase, sinusoidal supply of 240 V at 50 Hz. Assume that the converter output voltage with a firing angle a = 0 is the rated voltage of the motor.

(a) What external inductance, if any, should be in series with the armature so as to allow speed variation down to 500 rev/min with continuous current? Assume that the load torque is independent of speed.

[L_a = 52.2mH]

(b) Find the required firing angle. [α = 60°]

12. A DC motor has armature resistance of 0.045 Ω and inductance of 0.73 mH. It develops a back emf of 230 V when driven at 3500 rev/min. Its rated armature current is 89 A. The motor is to be supplied from a three-phase, 50 Hz, AC source through a three-phase, fully-controlled thyristor bridge converter.

(a) What should be the line-line voltage supply to the converter so that a maximum output DC voltage of 230V can be supplied to the motor?

[170.25 Volts]

(b) The output voltage of the converter for a firing angle α is given by

$$v(t) = \frac{3V_{max}}{\pi}\cos\alpha + \frac{6V_{max}}{\pi}\left[\left(\frac{\cos 7\alpha}{14} - \frac{\cos 5\alpha}{10}\right)\sin 6\omega_s t - \left(\frac{\sin 7\alpha}{14} - \frac{\sin 5\alpha}{10}\right)\cos 6\omega_s t\right]$$

where the second term is the dominant ripple voltage in the output, α is the firing angle of the converter and V_{max} is the peak of the supply voltage to the converter. It may be assumed that the ripple is maximum when $\alpha = 90°$. The ripple current in the motor causes extra losses and requires the motor to be de-rated. What is the de-rated current rating of the motor?

[79.22A]

(c) What should be the firing angle of the converter for the motor to develop maximum output torque at a speed of 600 rev/min?

[79.22°]

13. A three-phase, fully-controlled bridge rectifier is supplied from a 300V, 50 Hz supply. It is used to drive a separately excited dc motor of armature resistance R_a = 0.02 Ω and L_a = 0.002 H. The motor back emf constant K_E = 2.25 V/rad/sec. The motor rated current is 500A. The ac supply has negligible source inductance.

(a) Calculate the firing angle α, for the motor to run at a speed of 1500 rev/min at rated load.

[α = 26.3°]

(b) If the motor is transferred to an ac supply of the same voltage and frequency but having an inductance L_s of 1 mH/line, calculate the speed at which the motor will run for the same firing angle of part (a). The DC output voltage of the converter with source inductance L_s is given by

$$V_{dc} = \frac{3V_{max}}{\pi}\cos\alpha - \frac{3\omega L_s}{\pi} I_a$$

[861.5 rev/min]

14. A converter fed DC motor has a current limit of twice the full-load current and a voltage limit equal to the rated motor voltage. Calculate the fastest acceleration and deceleration the drive can have with and without regeneration. Motor data are:

R_a = 0.2 Ω; L_a = 0.05 H; J_T = 0.014 kg-m²; T_f = 5 Nm; D = 0 Nm/rad/sec,
Full load torque = 20 Nm, rated speed = 3000 rev/min, $K_E = K_T$ = 0.796 V/rad/sec.

[2500 rad/sec², -3214 rad/sec²]