Tutorial 2:

Q1) A 220 V, 500 A, 600 RPM separately excited motor has armature and field resistance of 0.02 and 10 Ω respectively. The load torque is given by the expression $T_L = 2000 - 2N$, N-m, where N is the speed in RPM. Speeds below the rated are obtained by the armature voltage control and speeds above rated are obtained by the field control.

(i) Calculate the motor terminal voltage and armature current when speed is 450 rpm
(ii) Calculate motor terminal voltage and current when the speed is 750 rpm.

Q2) A 2-pole separately excited dc motor has the ratings of 220 V, 100 A and 750 rpm. Resistance of the armature is 0.1 Ω. The motor has two field coils which are normally connected in parallel. It is used to drive a load whose torque is expressed as TL = 5000 – 0.3N, N-m where N is the motor speed in rpm. Speeds below and above rated are obtained by armature voltage control and by connecting the two field windings in series respectively.

(i) Calculate the motor armature current and speed when the armature voltage is reduced to 110 V
(ii) Calculate the motor speed and the current when the field coils are connected in series.

3) A 220 V, 1500 rpm, 50 A separately excited motor with armature resistance of 0.5 Ω, is fed from a 3-phase fully controlled rectifier. Available ac source has a line voltage of 440 V, 50 Hz. A star delta connected transformer is used to feed the armature so that the motor terminal voltage equals rated voltage when converter firing angle is zero.

(i) calculate the transformer turns ratio

(ii) Determine the value of firing angle when: (a) motor is running at 1200 rpm and the rated torque (b) When motor is running at 8000 rpm and twice the rated torque.

Assume continuous conduction.

SOLUTIONS:

1)

Solution

(i) At 450 rpm, $T_L = 2000 - 2 \times 450 = 1100$ N-m

At rated operation $E_1 = 220 - 500 \times 0.02 = 210$ V

$$\text{Rated torque} = \frac{E_1 I_{a1}}{\omega_{m1}} = \frac{210 \times 500}{600 \times 2\pi/60} = 1671 \text{ N-m}$$

For a torque of 1100 N-m, $I_{a2} = \dfrac{1100}{1671} \times 500 = 329$ A

At 450 rpm, $$E_2 = \frac{450}{600} \times 210 = 157.5$$

$$V = E_2 + I_{a2}R_a = 157.5 + 329 \times 0.02 = 164 \text{ V}$$

(ii) At 750 rpm $T_L = 2000 - 2 \times 750 = 500$ N-m

At this operating point, let the flux and armature current be ϕ' and I_a' respectively. Then

$$K_e \phi' I_a' = 500 \tag{i}$$

From rated operation

$$K_e \phi_1 = \frac{210}{600 \times 2\pi/60} = 3342$$

Further at 750 rpm, $\omega_m' = \dfrac{750}{60} \times 2\pi = 78.54$ and $V = K_e \phi' \omega_m' + I_a' R_a$

or $$220 = 78.54 K_e \phi' + 0.02 I_a'$$

Substituting from Eq. (i)

$$220 = 78.54 \times \frac{500}{I_a'} + 0.02 I_a'$$

or $$0.02 I_a'^2 - 220 I_a' + 39270 = 0$$

This equation has solutions 181.5 A and 21647 A. Ignoring the unfeasible value gives

$$I_a' = 181.5$$

From Eq. (i) $$K_e \phi' = \frac{500}{181.5} = 2.755$$

$$\text{Field voltage} = 220 \times \frac{K_e \phi'}{K_e \phi_1} = 220 \times \frac{2.755}{3.342} = 181.3 \text{ V}$$

2)

Solution

At rated operation, $E_1 = 220 - 100 \times 0.1 = 210$ V

$$\omega_{m1} = \frac{750}{60} \times 2\pi = 25\pi$$

$$K_e\phi_1 = K = \frac{E_1}{\omega_{m1}} = \frac{250}{25\pi} = 2.674$$

(i) Let the motor speed and current be N_2 and I_{a2}, respectively.

$$E_2 = K\omega_{m2} = 2.674 \times \frac{N_2 \times 2\pi}{60} = 0.28N_2$$

$$V = E_2 + I_{a2}R_a$$

or
$$110 = 0.28N_2 + 0.1I_{a2} \tag{1}$$

Since
$$T = T_L$$

$$KI_a = 500 - 0.3N$$

or
$$2.674I_{a2} = 500 - 0.3N_2$$

or
$$500 = 0.3N_2 + 2.674I_{a2} \tag{2}$$

Simultaneous solution of Eq. (1) and (2) gives

$$I_{a2} = 148.9 \text{ A} \quad \text{and} \quad N_2 = 339.7 \text{ rpm}$$

(ii) When field coils are connected in series

$$K = \frac{2.674}{2} = 1.337$$

If armature current and speeds are I_{a3} and N_3

$$E_3 = 1.337\,N_3 \times \frac{2\pi}{60} = 0.14\,N_3$$

$$V = E_3 + I_{a3}R_a'$$

or
$$220 = 0.14N_3 + 0.1I_{a3} \tag{3}$$

Since
$$T = T_L$$

$$1.337I_{a3} = 500 - 0.3N_3$$

or
$$500 = 0.3N_3 + 1.337I_{a3} \tag{4}$$

Simultaneous solution of Eqs. (3) and (4) yields

$$I_{a3} = 25.48 \text{ A} \quad \text{and} \quad N = 1553.2 \text{ rpm}$$

3)

Solution

For 3-phase fully-controlled rectifier from Eq. (5.97)

$$V_m = \frac{\pi}{3} \cdot \frac{V_a}{\cos\alpha}$$

For rated motor terminal voltage $\alpha = 0°$

$$V_m = \frac{\pi}{3} \frac{220}{\cos 0°} = 230.4 \text{ V}$$

rms converter input voltage between lines $= 230.4/\sqrt{2} = 162.9$ V

For star-delta transformer connection, ratio of turns between phase windings of primary and secondary $= \frac{440/\sqrt{3}}{162.9} = 1.559.$

(ii) (a) At 1500 rpm $\quad E = 220 - 0.5 \times 50 = 195$ V

At 1200 rpm $\quad E = \frac{1200}{1500} \times 195 = 156$ V

$$V_a = E + I_a R_a = 156 + 50 \times 0.5 = 181 \text{ V}$$

Since $\quad V_a = \frac{3}{\pi} V_m \cos\alpha$

$$\cos\alpha = \frac{\pi}{3} \cdot \frac{V_a}{V_m} = \frac{\pi}{3} \times \frac{181}{230.4} = 0.8227$$

or $\quad \alpha = 34.65°$

(b) At – 800 rpm $\quad E = \frac{-800}{1500} \times 195 = -104$ V

$$V_a = E + I_a R_a = -104 + 100 \times 0.5 = -54 \text{ V}$$

From Eq. (i) $\quad \cos\alpha = \frac{\pi}{3} \cdot \frac{V_a}{V_m} = \frac{\pi}{3} \times \frac{-54}{230.4} = -0.2454$

or $\quad \alpha = 104.20°$