ANNA UNIVERSITY SOLVED PROBLEMS

UNIT-I

① A motor drives two loads, one has rotational motion. It is Coupled to the motor through a reduction gear with a = 0.1 and efficiency of 90%. The load has a moment of inertia of 10kg-m2 and a torque of 10 N-m. Other load has translational motion and consists of 1000kg weight to be lifted up an uniform speed of 1.5 m/s. Coupling between this load and the motor has an efficienly of 85%. Motor has an inertia of 0.2 kg-m2 and runs at a constant speed of 1420 rpm. Determine equivalent inertia referred to the motor shaft and power developed by the motor. (APR/MAY 2011-16M)

Solution:-

The total moment of inertia referred to the motor shaft.

$$J = J_0 + a_1^2 J_1 + M_1 \left[\frac{V_1}{\omega_m}\right]^2$$

$J_0 = 0.2\,kg\text{-}m^2$, $a_1 = 0.1$, $J_1 = 10\,kg\text{-}m^2$

$V = 1.5\,m/s$ and $\omega_m = \frac{1420 \times \pi}{30}$

$\omega_m = 148.7\,rad/sec$

$$J = 0.2 + (0.1)^2 \times 10 + 1000\left[\frac{1.5}{148.7}\right]^2$$

$$= 0.4\,kg\text{-}m^2$$

$$T_L = \frac{a_1 T_{L1}}{\eta_1} + \frac{F_1}{\eta_1'}\left[\frac{V_1}{\omega_m}\right]$$

$\eta_1 = 0.9$, $a_1 = 0.1$, $T_{L1} = 10$ N-m, $\eta_1 = 0.85$.

$F_1 = 1000 \times 9.81$ N, $V_1 = 1.5$ m/s

$\omega_m = 148.7$ rad/sec

$$T_L = \frac{0.1 \times 10}{0.9} \times \frac{1000 \times 9.81}{0.85}\left[\frac{1.5}{148.7}\right]$$

$$T_L = 117.53 \text{ N-m}$$

Power developed $= T_L \omega_m = 117.53 \times 148.7$

$$\boxed{\text{power developed} = 17.48 \text{ kW}}$$

UNIT - II

① A 200V, 875 rpm, 150 A Separately excited DC motor has armature resistance of 0.06 Ω. It is fed from a 1 φ fully controlled rectifier with an ac Source Voltage of 220V, 50 Hz. Assuming Continuous Conduction, Calculate

(1) Firing angle for rated motor torque and 750 rpm.

(2) Firing angle for rated motor torque and (−500) rpm.

(Nov/DEC 2012 - 8M)

Given Data:-

Motor rating 200V, 875 rpm, 150 A

$R_a = 0.06\,\Omega$, AC Supply voltage $= 220$V, $f = 50$Hz

Solution:

At rated operation,

$$E_b = V - I_a R_a$$

(1) E_b at 750 rpm

$$E_b = \frac{750}{875} \times 191 = 163.7\,V$$

$$V_a = E_b + I_a R_a$$
$$= 163.7 + 150 \times 0.06$$
$$= 172.7\,V$$

Average output voltage of 1ϕ fully controlled rectifier is,

$$V_a = \frac{2V_m}{\pi} \cos\alpha$$

$$172.7 = \frac{2 \times \sqrt{2} \times 220}{\pi} \cos\alpha$$

$$\boxed{\alpha = 29.3^\circ}$$

(2) E_b at (−500 rpm)

$$E_b = \frac{-500}{875} \times 191 = -109.14\,V$$

Average output voltage,

$$V_a = E_b + I_a R_a$$
$$= -109.14 + 150 \times 0.06$$
$$= -100.14\,V$$

$$V_a = \frac{2V_m}{\pi} \cos\alpha$$

$$-100.14 = \frac{2 \times \sqrt{2} \times 220}{\pi} \times \cos\alpha$$

$$\boxed{\alpha = 120.36^\circ}$$

RESULT:-

(1) Firing angle at 750 rpm $\alpha = 29.3^\circ$

(2) " " " (−500 rpm) $\alpha = 120.36^\circ$

A Chopper used to control the speed of a separately excited DC motor, has supply voltage of 230V, $T_{ON} = 15ms$, $T_{OFF} = 5ms$. Assuming continuous conduction of motor current, calculate the average load current when the motor speed is 3000 rpm. Assume voltage constant $K_V = 0.5\,V/rad/sec$ and $R_a = 4\Omega$. (MAY/JUNE 2013 - 8M)

Given Data:-

$V_s = 230V$, $T_{ON} = 15ms$, $T_{OFF} = 5ms$

$N = 3000rpm$, $K_V = 0.5V/rad/sec$, $R_a = 4\Omega$

Solution:-

$$E_b = V_a - I_a R_a$$

$$V_a = \delta V_s$$

$$\delta = \frac{T_{ON}}{T} = \frac{T_{ON}}{T_{ON}+T_{OFF}} = \frac{15\times10^{-3}}{20\times10^{-3}} = 0.75$$

$$V_a = 0.75 \times 230$$

$$V_a = 172.5\,V$$

$$E_b = V_a - I_a R_a$$

$$= 172.5 - I_a \times 4$$

But, $E_b = K_V \omega_m$

$$= 0.5 \times \frac{2\pi \times 3000}{60}$$

$$E_b = 157\,V$$

∴ Motor load current,

$$I_a = \frac{V_a - E_b}{R_a} = \frac{172.5 - 157}{4}$$

$$\boxed{I_a = 3.87\,A}$$

(3) A 220V, 1500 rpm, 50A 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 440V, 50Hz. A star delta connected transformer is used to feed the armature so that motor terminal voltage equals rated voltage when converter firing angle is zero.

(i) Calculate transformer turns ratio.

(ii) Determine the value of firing angle when

(1) Motor is running at 1200rpm and rated torque;

(2) When motor is running at 800rpm and twice the rated torque. Assume continuous conduction. (NOV/DEC 2013 – 16M)

Solution:

For 3φ Fully Controlled Rectifier,

$$V_{ml} = \frac{\pi}{3} \times \frac{V_a}{\cos\alpha}$$

For rated motor terminal voltage firing angle $\alpha = 0$

$$V_{ml} = \frac{\pi}{3} \times \frac{220}{\cos 0} = 230.4\text{ V}$$

RMS converter input voltage between lines

$$V_L = \frac{V_{ml}}{\sqrt{2}} = \frac{230.4}{\sqrt{2}} = 162.9\text{ V}$$

(i) For star-delta transformer connection, the turns ratio between phase windings of primary and secondary,

$$K = \frac{440/\sqrt{3}}{162.9} = 1.559$$

(ii) (1) At 1500 rpm, back emf E_{b1}

$$E_{b1} = V - I_a R_a$$
$$= 220 - 50 \times 0.5$$
$$= 195\,V$$

At 1200 rpm $E_{b2} = \frac{1200}{1500} \times 195 = 156\,V$

Average output voltage,

$$V_a = E_{b2} + I_a R_a$$
$$= 156 + 50 \times 0.5$$
$$V_a = 181\,V$$

Since $V_a = \frac{3 V_{ml}}{\pi} \cos\alpha$

$$\cos\alpha = \frac{\pi}{3} \times \frac{V_a}{V_{ml}} = \frac{\pi}{3} \times \frac{181}{230.4} = 0.8227$$

$$\boxed{\text{Firing angle } \alpha = 34.65^\circ}$$

(2) At 800 rpm, back emf

$$E_{b2} = \frac{800}{1500} \times 195 = 104\,V$$
$$I_a = 2 \times 50 = 100\,A$$

Average output voltage,

$$V_a = E_{b2} + I_a R_a$$
$$= 104 + 100 \times 0.5$$
$$= 154\,V$$

$$\cos\alpha = \frac{\pi}{3} \times \frac{V_a}{V_{ml}} = \frac{\pi}{3} \times \frac{154}{230.4}$$

$$\cos\alpha = 0.6999$$

$$\boxed{\text{Firing angle } \alpha = 45.57^\circ}$$

① A 50kW, 240V, 1700 rpm separately excited DC Motor is controlled by a converter. The field current is maintained at $I_f = 1.4$ A and the machine back emf constant is $K_v = 0.91$ V/A rad/s. The armature resistance is $R_m = 0.1\ \Omega$ and the viscous friction constant is $B = 0.3$ Nm/rad/s. The amplification of the speed sensor is $K_1 = 95$ mV/rad/s and the gain of the power controller is $K_2 = 100$.

(i) Determine the reference voltage V_r to drive the motor at the rated speed.

(ii). If the reference voltage is kept unchanged, determine the speed at which the motor develops rated torque. (NOV/DEC 2012 - 16M)

Solution:

Field current $I_f = 1.4$ A, $k_v = 0.91$ V/A rad/sec

$k_1 = 95$ mV/rad/sec, $k_2 = 100$, $R_m = 0.1\ \Omega$,

$B = 0.3$ N-m/rad/sec, $\omega_{rated} = 1700 \times \frac{2\pi}{60}$

$= 178.02$ rad/sec

(i) Rated torque,

$$T_1 = \frac{50 \times 1000}{178.02} = 280.87 \text{ N-m}$$

Since $V_a = k_2 V_r$, for open loop control,

$$\frac{\omega}{V_a} = \frac{\omega}{k_2 V_r} = \frac{K_v I_f}{R_m B + (K_v I_f)^2}$$

$$= \frac{0.91 \times 1.4}{0.1 \times 0.3 + (0.91 \times 1.4)^2}$$

$$= 0.7707$$

⑧ At rated speed,

$$V_a = \frac{\omega}{0.7707} = \frac{178.02}{0.7707} = 230.98\,V$$

Feed back voltage,

$$V_b = K_1 \omega$$
$$= 95 \times 10^{-3} \times 178.02$$
$$= 16.912\,V$$

With closed loop control,

$$(V_r - V_b) K_2 = V_a$$

$$(V_r - 16.912) \times 100 = 230.98$$

$$\boxed{V_r = 19.222\,V}$$

(ii) For $V_r = 19.222\,V$ and $\Delta T_L = 280.87$ N-m

$$\Delta\omega = -\frac{R_m}{R_m B + (K_v I_f)^2 + K_1 K_2 K_v I_f} \times \Delta T_L$$

$$= -\frac{0.1 \times 280.87}{0.1 \times 0.3 + (0.91 \times 1.4)^2 + 95 \times 10^{-3} \times 100 \times 0.91 \times 1.4}$$

$$= -2.04 \text{ rad/sec.}$$

The speed at rated torque,

$$\omega = 178.02 - 2.04$$
$$= 175.98 \text{ rad/sec}$$

$$\boxed{N = 1680.5 \text{ rpm}}$$

(1) A 2.8KW, 400V, 50Hz, 4 pole, 1370 rpm, delta connected squirrel cage induction motor has following parameters referred to the stator: $R_s = 2\Omega$; $R_r = 5\Omega$; $X_s = X_r = 5\Omega$, $X_m = 80\Omega$. Motor speed is controlled by stator voltage control. When driving a fan load it runs at rated speed at rated voltage. Calculate motor terminal voltage, current and torque at 1200rpm.

(MAY/JUNE 2012 - 16M)

Given Data:-

Power rating of the motor = 2.8KW,

Voltage $V = 400V$, $f = 50Hz$, $P = 4$, $N = 1370$ rpm,

$R_s = 2\Omega$, $R_r = 5\Omega$, $X_s = X_r = 5\Omega$, $X_m = 80\Omega$.

Solution:

Synchronous speed $N_s = \dfrac{120f}{P} = \dfrac{120 \times 50}{4}$

$N_s = 1500$ rpm

$\omega_s = \dfrac{1500 \times 2\pi}{60} = 157.07$ rad/sec

At full load, slip $S = \dfrac{N_s - N}{N_s} = \dfrac{1500 - 1370}{1500}$

$= 0.0866$

The torque equation is,

$$T = \frac{3}{\omega_s} \cdot \frac{V^2 R_r / s}{\left[R_s + \frac{R_r}{s}\right]^2 + (X_s + X_r)^2}$$

$$= \frac{3}{157.07} \times \frac{400^2 \times 5 / 0.0866}{\left(2 + \frac{5}{0.0866}\right)^2 + (5+5)^2}$$

$T = 48.09$ N-m.

For a Fan type load torque is Proportional to $(\text{Speed})^2$

Thus $T_L = k(1-s)^2$

$T_L \propto \omega_m^2 \quad T_L \propto (\omega_s(1-s))^2$

$T_L \propto \omega_s^2 (1-s)^2$

$T_L = k(1-s)^2$

At full load, $T = T_L$

$k(1-0.0866)^2 = 48.13$

$k = 57.7$

Hence, $T_L = 57.7(1-s)^2 \ldots\ldots (1)$

At 1200 rpm,

Slip $s = \dfrac{1500-1200}{1500} = 0.2$

At this speed from equation (1)

$T_L = 57.7(1-0.2)^2$

$\boxed{T_L = 36.9 \text{ N-m}}$

Now, $T_L = 36.9 = \dfrac{3}{157.07} \times \dfrac{V^2 \times 5/0.2}{\left(2+\frac{5}{0.2}\right)^2 + (5+5)^2}$

which gives $\boxed{V = 253.2V}$

$$\bar{I}_r = \frac{V}{\left(R_r + \frac{R_r'}{s}\right) + j(X_s + X_r')}$$

$$= \frac{253.2}{\left(2+\frac{5}{0.2}\right) + j10}$$

$$= 8.246 - j3.054$$

$$\bar{I}_m = \frac{V}{jX_m} = \frac{253.2}{j\ldots} = j3.165$$

$$\bar{I}_s = \bar{I}_r + \bar{I}_m$$

$$= 8.246 - j3.054 - j3.165$$

$$= 10.328 \angle -37^\circ A$$

Line current $I_L = \sqrt{3} \times I_s$

$$= \sqrt{3} \times 10.328 = 17.89 A$$

$$\boxed{I_L = 17.89 A}$$

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(2) A three phase 60kW, 4000 rpm, 460V, 60Hz, 2 pole star connected induction motor has the following parameters: $R_s = 0$, $R_r = 0.28\Omega$, $X_s = 0.23\Omega$, $X_r = 0.3\Omega$ and $X_m = 11\Omega$. The motor is controlled by varying the supply frequency. If the breakdown torque requirement is 70 Nm, calculate supply frequency and speed ω_m at the maximum torque. (NOV/DEC 2013 - 8M)

Solution:

$$V_1 = \frac{460}{\sqrt{3}} = 265.6 V$$

$$\omega_b = 2\pi f_b = 2\pi \times 60 = 377 \text{ rad/sec}$$

$P = 2$, $P_o = 60{,}000W$, $N = 4000$ rpm

$$\omega_m = 4000 \times \frac{2\pi}{60} = 418.88 \text{ rad/sec}$$

$$P_o = T_{mb}\, \omega_m$$

$$T_{mb} = \frac{P_o}{\omega_m} = \frac{60{,}000}{418.88} = 143.23 N\text{-}m$$

The Supply frequency,

$$\beta = \sqrt{\frac{T_{mb}}{T_m}} = \sqrt{\frac{143.23}{70}} = 1.43$$

$$\omega_s = \beta\,\omega_b = 1.43 \times 377$$

$$= 539.29 \text{ rad/sec}$$

$$\omega_s = \frac{2\omega}{P}$$

$$\omega = \frac{\omega_s P}{2} = \frac{539.29 \times 2}{2}$$

$$\omega = 539.29 \text{ rad/sec}$$

$$\omega = 2\pi f$$

$$f = \frac{\omega}{2\pi} = \frac{539.29}{2\pi} = 85.83 \text{ Hz}$$

$$\boxed{f = 85.83 \text{ Hz}}$$

The Speed ω_m at the maximum torque

$$S_m = \frac{R_r/\beta}{X_s + X_r} = \frac{0.28/1.43}{0.23 + 0.3} = 0.369$$

$$\omega_m = \omega_s(1 - S_m)$$

$$= 539.29(1 - 0.369)$$

$$\omega_m = 340.05 \text{ rad/sec}$$

$$N = 340.05 \times \frac{60}{2\pi} = 3247.23 \text{ rpm}$$

$$\boxed{\text{Speed } N = 3247.23 \text{ rpm}}$$