2018 Fall

5.b

A 440 V, 50 Hz, 6 pole, Y-connected wound-rotor induction motor has following parameters referred to stator:

$$R_s = 0.5\ \Omega, R_r' = 0.4\ \Omega, X_s = X_r' = 1.2\ \Omega, X_m = 50\ \Omega$$

An external resistance is inserted into the rotor circuit so that maximum torque is produced at $s_m = 2$. The motor, which was initially operating on no-load is being braked by 1-phase ac dynamic braking with three lead connection. Calculate the braking current and torque as a ratio of their full load values for 950 rpm.

Solution

$$s_m = \frac{R_r'}{\sqrt{R_s^2 + (X_s + X_r')^2}}$$

For $s_m = 2$

$$2 = \frac{R_r'}{\sqrt{(0.5)^2 + (2.4)^2}} \quad \text{or} \quad R_r' = 4.9\ \Omega$$

$$\text{Synchronous speed} = \frac{120 f}{P} = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

At 950 rpm $$s = \frac{1000 - 950}{1000} = 0.05$$

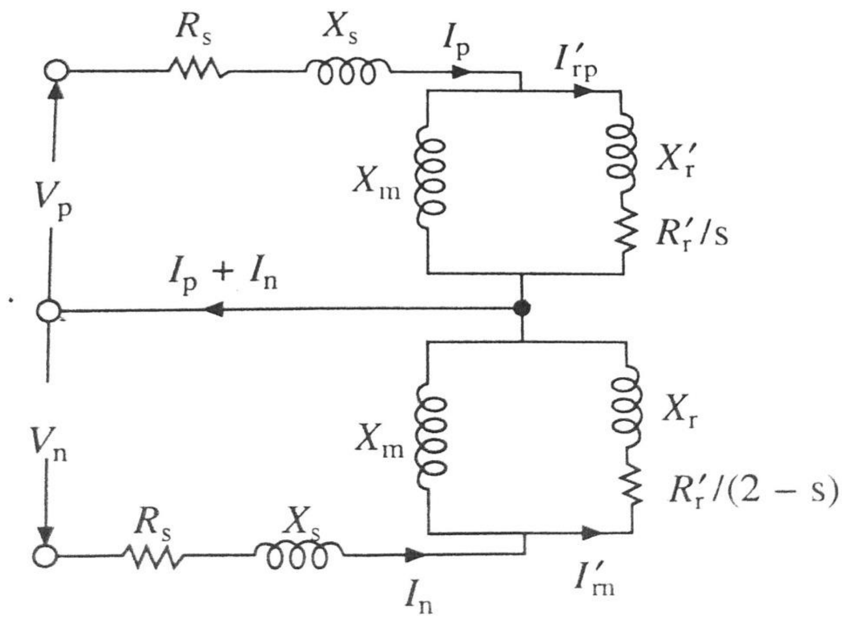

Fig. 6.17 Equivalent circuit for three lead connection

From equivalent circuit of Fig. 6.17, impedance of positive sequence part of the equivalent circuit

$$Z_p = R_s + jX_s + \frac{jX_m\left(\frac{R'_r}{s} + jX'_r\right)}{\frac{R'_r}{s} + j(X'_r + X_m)} = 0.5 + j1.2 + \frac{j50\left(\frac{4.9}{0.05} + j1.2\right)}{\frac{4.9}{0.05} + j(51.2)}$$

$$= 0.5 + j1.2 + 20.03 + j39.5$$

$$= 20.53 + j40.7 = 45.6 \angle 63.23° \ \Omega$$

$$\bar{I}_p = \frac{254/\sqrt{3}}{45.6 \angle 63.23°} = 3.35 \angle -63.23°$$

$$I'_{rp} = \bar{I}_p \times \frac{jX_m}{R'_r/s + j(X'_r + X_m)}$$ [∵ current divider rule]

$$= 3.55 \angle -63.23° \times \frac{j50}{\frac{4.9}{0.05} + j(51.2)} = 1.606 \angle -0.8°$$

$$T_p = \frac{3I'^2_{rp} R'_r/s}{\omega_{ms}} = \frac{3\,(1.606)^2 \times 4.9/0.05}{104.72} = 7.24 \text{ N-m}$$

$$Z_n = R_s + jX_s + \frac{jX_m\left(\frac{R'_r}{2-s} + jX'_r\right)}{\frac{R'_r}{2-s} + j(X'_r + X_m)} = 0.5 + j1.2 + \frac{j50\left(\frac{4.9}{1.95} + j1.2\right)}{\frac{4.9}{1.95} + j(51.2)}$$

$$= 0.5 + j1.2 + 2.39 + j1.29 = 2.89 + j2.49 = 3.81 \angle 40.75° \ \Omega$$

$$\bar{I}_n = \frac{254/\sqrt{3}}{3.81 \angle 40.75°} = 42.52 \angle -40.75°$$

$$\bar{I}'_{rn} = \bar{I}_n \times \frac{jX_m}{\frac{R'_r}{2-s} + j(X_m + X'_r)} = 42.52 \angle -40.75° \times \frac{j50}{\frac{4.9}{1.95} + j51.2}$$

$$= 41.45 \angle -37.95°$$

$$T_n = -\frac{3I'^2_{rn}R'_r/(2-s)}{\omega_{ms}} = -\frac{3(41.45)^2 \times 4.9/1.95}{104.72} = -123.7 \text{ N-m}$$

$$T = 7.24 - 123.7 = -116.45 \text{ N-m}$$

Motor current $I = |\bar{I}_p + \bar{I}_n| = |3.55 \angle -63.23 + 42.52 \angle -40.75| = 45.83$ A

Full load motor current

$$I_f = \frac{440/\sqrt{3}}{\sqrt{\left(0.5 + \frac{0.4}{0.05}\right)^2 + (2.4)^2}} = 28.76 \text{ A}$$

Full load motor torque

$$T_f = \frac{3 \times (28.76)^2 \times 0.4/0.05}{104.72} = 189.59 \text{ N-m}$$

Now

$$\frac{I}{I_f} = \frac{45.83}{28.76} = 2.295$$

$$\frac{T}{T_f} = \frac{116.45}{189.59} = 0.614$$

2016 spring

4.b

A 2200 V, 50 Hz, 3-phase, 6 pole, Y-connected, squirrel-cage induction motor has following parameters:

$$R_s = 0.075\ \Omega, R_r' = 0.12\ \Omega, X_s = X_r' = 0.5\ \Omega$$

The combined inertia of motor and load is 100 kg-m^2.

(i) Calculate time taken and energy dissipated in the motor during starting.

(ii) Calculate time taken and energy dissipated in the motor when it is stopped by plugging.

(iii) what resistance should be inserted in the rotor to stop motor by plugging in the minimum time? Also calculate stopping time and energy dissipated in the motor during braking.

Solution

(i)

$$s_m = \frac{R_r'}{\sqrt{R_s^2 + (X_r' + X_s)^2}} = \frac{0.12}{\sqrt{(0.075)^2 + 1^2}} = 0.1197$$

$$\omega_{ms} = \frac{4\pi f}{p} = \frac{4\pi \times 50}{6} = 104.72 \text{ rad/sec}$$

$$T_{max} = \frac{3}{2\omega_{ms}} \times \left[\frac{V^2}{R_s + \sqrt{R_s^2 + (X_s + X_r')^2}}\right]$$

$$= \frac{3}{2 \times 104.72} \times \left[\frac{(2200/\sqrt{3})^2}{0.075 + \sqrt{(0.075)^2 + 1}}\right] = 21441 \text{ N-m}$$

$$\tau_m = \frac{J\omega_{ms}}{T_{max}} = \frac{100 \times 104.72}{21441} = 0.4884 \text{ sec}$$

The starting time is given by

$$t_s = \tau_m\left[\frac{1}{4s_m} + 1.5\, s_m\right] = 0.4884\left[\frac{1}{4 \times 0.1197} + 1.5 \times 0.1197\right] = 1.1077 \text{ sec}$$

Energy dissipated in the motor is given as

$$E_s = \frac{1}{2} J\omega_{ms}^2 \left(1 + \frac{R_s}{R_r'}\right) = \frac{1}{2} \times 100 \times (104.72)^2 \cdot \left(1 + \frac{0.075}{0.12}\right)$$

$$= 891 \text{ kilo-watt-sec}$$

(ii) time required to stop by plugging Is given by

$$t_b = \tau_m\left[0.345\, s_m + \frac{0.75}{s_m}\right]$$

$$= 0.4884\left[0.345 \times 0.1197 + \frac{0.75}{0.1197}\right] = 3.08 \text{ sec}$$

Energy dissipated in the machine during braking is given as

$$E_b = \frac{3}{2} J\omega_{ms}^2 \left(1 + \frac{R_s}{R_r'}\right)$$

$$= \frac{3}{2} \times 100 \times (104.72)^2 \times \left(1 + \frac{0.075}{0.12}\right) = 2673 \text{ kilo-watt sec}$$

Stopping time has a minimum value of 1.027 τ_m, Thus

t_b=1.027*0.4884=0.5 sec

if external resistance is R_e,

$$R'_r + R_e = 1.47\,(X_s + X'_r) = 1.47$$

or
$$R_e = 1.47 - 0.12 = 1.35\ \Omega$$

Energy dissipated in the motor and external resistance remains same as in (ii), i.e. 2673 kilo-watt-sec. Energy dissipated in the external resistor

$$E_e = \frac{3}{2} J\omega_{ms}^2 \left(\frac{R_e}{R_e + R'_r}\right) = \frac{3}{2} \times 100 \times (104.72)^2 \times \left(\frac{1.35}{1.47}\right)$$

$$= 1510.67 \text{ kilo-watt-sec}$$

Energy dissipated in the motor

$$E_b = 2673 - 1510.67 = 1162.33 \text{ kilo-watt-sec}$$

It is interesting to note that insertion of optimum rotor resistance has while reduced the stopping time from 3.08 to 0.5 sec, the energy dissipation in motor has reduced from 2673 kilo-watt-sec to 1112 kilo-watt-sec.