Starting and plugging

We have,

$$S_m = \frac{R_r'}{\sqrt{R_s^2 + (X_s + X_r')^2}} \quad \text{---} (1)$$

The starting time is given by

$$t_s = \tau_m \left[\frac{1}{4S_m} + 1.5 S_m \right] \quad \text{---} (2)$$

$$\text{where, } \tau_m = \frac{J\omega_{ms}}{T_{max}}$$

Minimum starting time can be found as

$$\frac{d(t_s)}{dS_m} = 0 \quad \Rightarrow S_m = 0.4$$

$$\therefore (t_s)_{min} = 1.22\, \tau_m \quad \text{---} (3)$$

From eq^n (1) when R_s is negligible, rotor resistance required to start the motor in minimum time is

$$(R_{rm}')_s = 0.4 (X_s + X_r') \quad \text{---} (4)$$

The time required for stopping by plugging when initially running at synchronous speed can be expressed as

$$t_b = \tau_m \left[0.345 S_m + \frac{0.75}{S_m} \right] \quad \text{---- (5)}$$

So the minimum time can be found as

$$\frac{d(t_b)}{dS_m} = 0 \Rightarrow S_m = 1.47$$

$$\therefore (t_b)_{min} = 1.027\, \tau_m \quad \text{--- (6)}$$

Corresponding value of rotor resistance is

$$(R'_{rm})_b = 1.47 (X_s + X'_r) \quad \text{--- (7)}$$

The time required for speed reversal by plugging is

$$t_r = \tau_m \left[3.69 S_m + 1/S_m \right]$$

So the minimum reversal time can be found as

$$\frac{d(t_r)}{dS_m} = 0 \Rightarrow S_m = 0.52$$

$$\therefore (t_r)_{min} = 2.88\, \tau_m$$ And, $(R'_{rm})_r = 0.52 (X_s + X'_r)$

Calculation of energy losses

Energy loss in rotor circuit during starting is

$$E_{sr} = \frac{1}{2} J \omega_{ms}^2 \quad \text{---} (1)$$

Energy loss in stator circuit during starting is

$$E_{ss} = \frac{1}{2} J \omega_{ms}^2 \left(\frac{R_s}{R_r'} \right)$$

Total energy loss in machine during starting under no load is

$$E_s = E_{sr} + E_{ss} = \frac{1}{2} J \omega_{ms}^2 \left(1 + \frac{R_s}{R_r'} \right)$$

Energy loss in rotor circuit during starting under constant load torque T_L is

$$E_{sr} = -J \omega_{ms}^2 \int_1^{0.05} \left[1 + \frac{T_L}{T_M - T_L} \right] s \cdot ds$$

Energy loss in rotor circuit during plugging is

$$E_{pr} = \frac{3}{2} J \omega_{ms}^2$$

Similarly total energy loss during plugging under no load is

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

Energy loss in rotor circuit during plugging under constant load torque T_L is

$$E_{pr} = J \omega_{ms}^2 \int_{\alpha}^{1} \left[1 + \frac{T_L}{T_m - T_L} \right] s \, ds$$

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,

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

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

The minimum stopping time is

$$(t_b)_{min} = 1.027\, \tau_m = 1.027 \times 0.484 = 0.5 \text{ sec}$$

If external resistance is R_e

$$R_r' + R_e = 1.47\,(X_s + X_r') = 1.47\,(0.5 + 0.5) = 1.47\,\Omega$$

$$\Rightarrow R_e = 1.47 - R_r' = 1.47 - 0.12 = 1.35\,\Omega$$

Energy dissipated in the external resistor can be derived as,

Energy loss in rotor circuit during stopping under no load is

$$E_{pr} = \frac{3}{2} J \omega_{ms}^2$$

$$\frac{\text{Energy loss in external resistor } (E_{pe})}{\text{Energy loss in rotor circuit } (E_{pr})} = \frac{3\int_0^{t_b} (I_r')^2 R_e\, dt}{3\int_0^{t_b} (I_r')^2 (R_r' + R_e)\, dt}$$

$$\Rightarrow \frac{E_{pe}}{E_{pr}} = \frac{R_e}{R_r' + R_e}$$

$$\Rightarrow E_{pe} = \frac{3}{2} J \omega_{ms}^2 \frac{R_e}{R_r' + R_e}$$

So, $E_{pe} = \frac{3}{2} \times 100 \times (104.72)^2 \times \frac{1.35}{1.47} = 1510.67$ KW-sec

Total energy dissipated will be same as in (ii)

So, Energy dissipated in motor apart from external resistor will be

$$E_b' = E_b - E_{pe} = 2673 - 1510.67$$
$$= 1162.33 \text{ KW-sec}$$

It is to be noted that insertion of optimum external resistance in rotor circuit has reduced the stopping time from 3.08 to 0.5 sec and the energy dissipated in the motor has reduced from 2673 to 1162.33 KW-sec