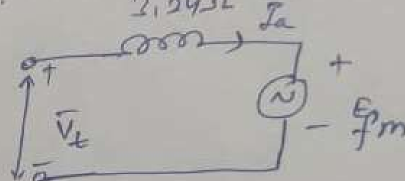
Tutorial 11

1. A 1000 kW, 3-phase, Y-connected, 3.3 kV, 24-pole, 50 Hz synchronous motor has a synchronous reactance of 3.24 Ω per phase; the resistance being negligible. The motor is fed from an infinite bus at 3.3 kV. Its field excitation is adjusted to result in unity pf operation at rated load. Maximum torque that the motor can deliver with its excitation remaining constant at this value is ________.

Soln: The operation of motor at infinite bus-bars is shown in the figure:-



$V_t = 3300/\sqrt{3} = 1905\ V$

$$I_a = \frac{1000 \times 1000}{\sqrt{3} \times 3300 \times 1} = 175\ A$$

$\cos\phi = 1, \quad \phi = 0°$

Taking the terminal voltage as reference,

$$\bar{V}_t = 1905 \angle 0°\ V$$
$$\bar{I}_a = 175 \angle 0°\ A$$

Then, the excitation emf is computed as:-

$$E_{fm} = 1905 \angle 0° - j\,175 \angle 0° \times 3.24$$
$$= 1905 - j\,567$$

$\therefore E_{fm} = 1987\ V$

Excitation remaining fixed, the max. power delivered by the motor is:-

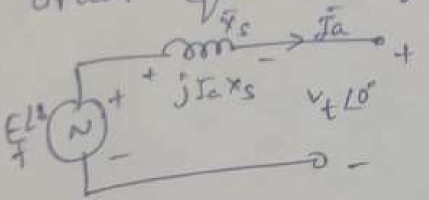
$$P_{e,max} = P_{m,max}\ (\text{gross})$$
$$= 3 \times \frac{V_t E_f}{X_{sm}} = 3 \times \frac{1905 \times 1987}{3.24 \times 1000}$$
$$= 3505\ kW \quad (3\text{-phase})$$

$$\omega_{sm} = \frac{120 \times 50 \times 2\pi}{24 \times 60} = 26.18\ rad/s$$

$$T_{max} = \frac{3505 \times 1000}{26.18} = 133.9 \times 10^3\ Nm$$

2. A 3- phase 10 kVA, 400 V, 4-pole, 50 Hz star connected synchronous generator has synchronous reactance of 16 Ω and negligible resistance. The machine is connected to 400 V infinite bus. The magnitude of per phase excitation emf when machine is delivering rated kVA at 0.8 pf lagging is-

Soln: The circuit equivalent of machine is drawn as.



$$I_a = \frac{10\times10^3}{\sqrt{3}\times400} = 14.43\ A$$

p.f angle, $\phi = \cos^{-1}0.8 = 36.9^\circ$ lag

$$\bar{I}_a = 14.43\angle-36.9^\circ$$

$$V_t = \frac{400}{\sqrt{3}} = 231V$$

from the ckt, equivalent, $\bar{E}_f = 231\angle0^\circ + j14.43\angle-36.9^\circ\times16$

$$= 231 + 231\angle53.1^\circ$$

$$= 369.7 + j184.7$$

i.e $E_f = 413.3\ \angle26.5^\circ$

3. A 40 kVA, 600 V star-connected synchronous motor has armature effective resistance of 0.8 Ω and synchronous reactance of 8 Ω. It has stray load loss of 2 kW. The motor is connected at 600 V bus while supplying a shaft load of 30 kW. If it is drawing rated current at leading pf, Calculate the motor efficiency in %.

Solⁿ: Shaft load, $P_m(\text{net}) = 30\,kW$

Stray Loss, $P_{st} = 2\,kW$

Mechanical power developed, $P_m(\text{dev}) = 30 + 2 = 32\,kW$

Armature current, $I_a = I_a(\text{rated}) = \dfrac{40 \times 10^3}{\sqrt{3} \times 600}$

$= 38.5\,A$

Ohmic loss, $3 I_a^2 R_a = 3 \times (38.5)^2 \times 0.8 \times 10^{-3}$

$= 3.557\,kW$

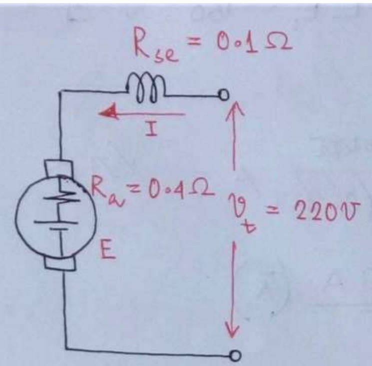
Electrical power input, $P_e(in) = 32 + 3.557$

$= 35.557\,kW$

Efficiency, $\eta = 1 - \left(\dfrac{2 + 3.557}{35.557}\right) = 84.4\%$

4. A 220 V DC series motor runs by drawing a current of 30 A from the supply. Armature and field circuit resistances are 0.4Ω and 0.1Ω, respectively. The load torque of motor varies as the square of its speed. The flux in the motor may be taken as being proportional to the armature current. To reduce the speed of the motor by 50%, the resistance (in ohms) that should be added in series with the armature is ________.

1.



at $I = 30$ A

$$E = v_t - I(R_a + R_{se})$$
$$= [220 - 30(0.4 + 0.1)]\,V$$
$$= 205\,V$$

from the relationships among the D/c machine Quantities, we know,

$$E = K\phi\omega \qquad T = K\phi I_a$$

[ω = Speed of the m/c, T = Torque generated]

again $T \propto \omega^2$ & $\phi \propto I_a$ } $\Rightarrow K_2 I_a^2 = K_3\omega^2$

[at 50% speed, I_a will also be 50% i.e. 15 A]

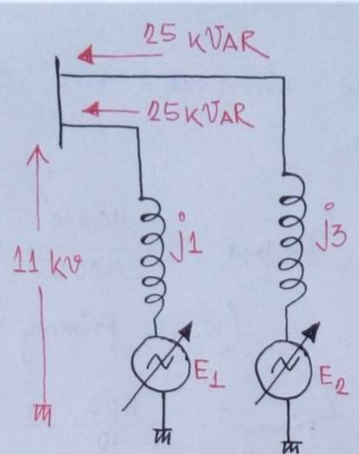
Since $\phi \propto I_a \rightarrow \phi$ will be halved

$E_1 = k\phi_1\omega_1$; $E_2 = k\phi_2\omega_2$ $\left[\phi_2 = \phi_1/2 \,;\, \omega_2 = \omega_1/2\right]$

$$\therefore\ E_2 = E_1/4 = 205/4\,V = 51.25\,V$$

$$R_{Additional} = \left[\frac{220 - 51.25}{15} - (0.4 + 0.1)\right]\Omega = \underline{\underline{10.75\,\Omega}}\ (\bar{A})$$

5. Two parallel connected, three-phase, 50Hz, 11 kV, star-connected synchronous machines, A and B, are operating as synchronous condensers. They together supply 50 MVAR to a 11 kV grid. Current supplied by both the machines are equal. Synchronous reactances of machine A and machine B are 1Ω and 3Ω , respectively. Assuming the magnetic circuit to be linear, the ratio of excitation emf of machine A to that of machine B (i.e. E_A/E_B) is –



$$\sqrt{3}\, v\, I \sin \overset{90^\circ}{\cancel{\theta}} = Q$$

$$I = \frac{25 \times 10^3}{\sqrt{3} \times 11}$$

$$= 1.312 \text{ kA}$$

$$\therefore \bar{I} = 1.312 \angle 90^\circ \text{ kA}$$

$$E_1 = 11/\sqrt{3} \angle 0^\circ - \bar{I} . X \quad [\text{motor eq}^n]$$

$$= 11/\sqrt{3} - (1.312\angle 90^\circ) . 1\angle 90^\circ = 7.662 \text{kV}$$

$$E_2 = 11/\sqrt{3} - (1.312\angle 90^\circ) \times 3\angle 90^\circ = 10.286 \text{ kV}$$

$$\text{ratio of excitation} = \frac{E_1}{E_2} = \frac{7.662}{10.286} = \underline{\underline{0.745}} \; (\bar{A})$$