18 pts

Question 1

(a) A balanced, symmetrical, 10HP, 3-phase, Y-connected, 60 Hz, 208 Volt (line-line) induction motor has a no-load line current of 6 Amps and rated line current of 10 Amps. The rated speed is 1720 RPM. You may assume negligible core loss, stator copper loss, and stator/rotor leakages. (1 HP = 746W)

i. How many poles does this induction machine have?

ii. Find the frequency of the rotor currents during rated operation

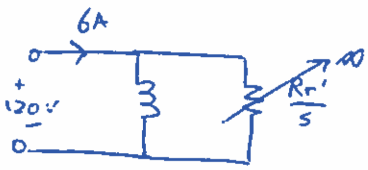
iii. Estimate the magnetizing reactance and the rotor resistance referred to the stator

i) Rated speed : 1720 RPM

⇒ Synchronous speed : 1800 RPM ⇒ $\boxed{P=4}$

ii) $s = \frac{1800-1720}{1800} = \frac{2}{45}$ ⇒ $f_r = s \cdot f_s = \boxed{2.67\ Hz}$

iii) No load



$X_m = \frac{120V}{6A}$ ⇒ $\boxed{X_m = 20\Omega}$

Rated Load

Method 1

$P_{shaft} = 746 \times 10 = 7460W$

$P_{AG} = \frac{7460}{1-s} = 7806.9767W$

$\frac{3V^2}{R_r'/s} = 7806.97W \rightarrow \frac{R_r'}{s} = \frac{3(V^2)}{7806.97}$ ⇒ $\boxed{R_r' = 0.246\Omega}$

two possible solutions

Method 2

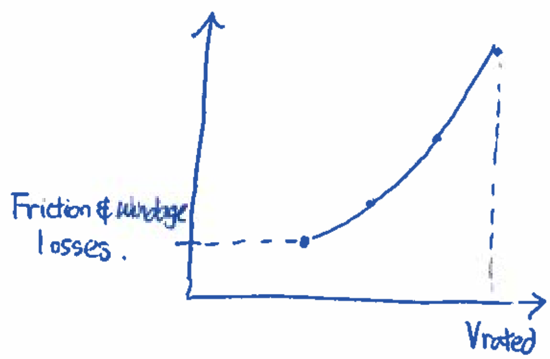
$I_r' = 8A \quad (8 - j6 = 10\ A)$

$V = I_r' \left(\frac{R_r'}{s}\right)$ ⇒ $\boxed{R_r' = 0.67\Omega}$

12 pts

(b) In the induction machine experiment, input power was measured for no-load conditions at various input voltages. Explain how the friction and windage losses can be estimated with these measurements.

From the measured input power at each of the test voltage points, stator conduction losses can be subtracted. Then, the curve can be extrapolated to find the input power at $V=0$



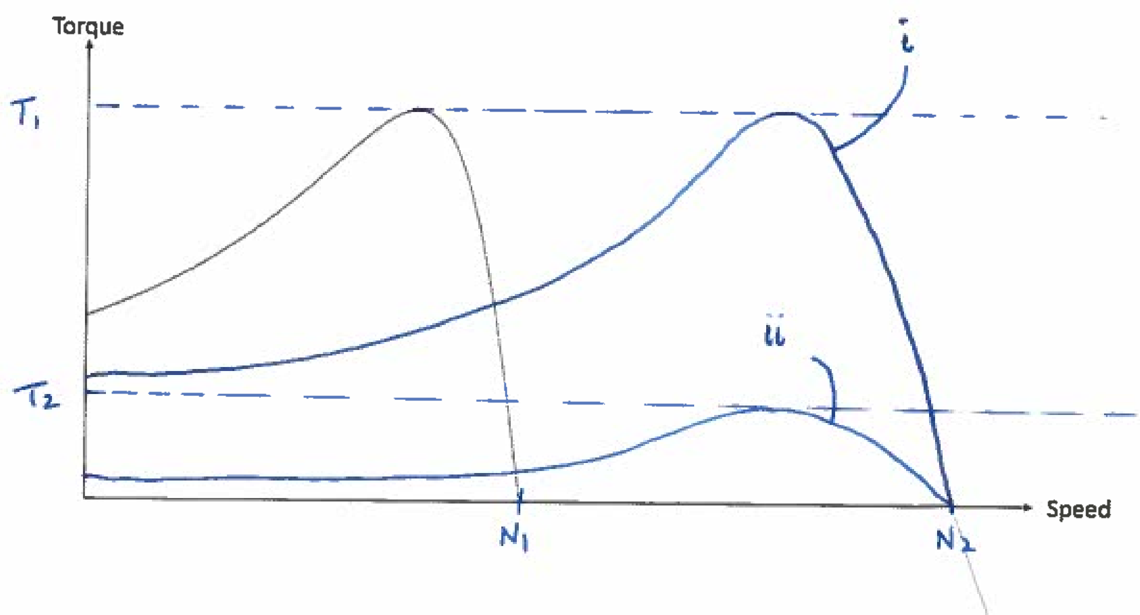
(c) Given below is a torque-slip curve of a certain induction machine. Superimpose a modified curve for two given scenarios:

i. Drive frequency is doubled (with V/Hz control)

ii. Drive frequency is doubled (without V/Hz control)

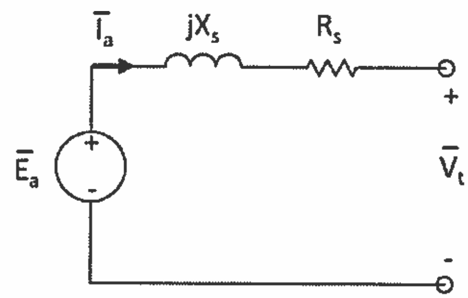
Label the speed and maximum torque accordingly.

$T_1 = 4 \cdot T_2$
$N_2 = 2 \cdot N_1$



20 pts

Question 2



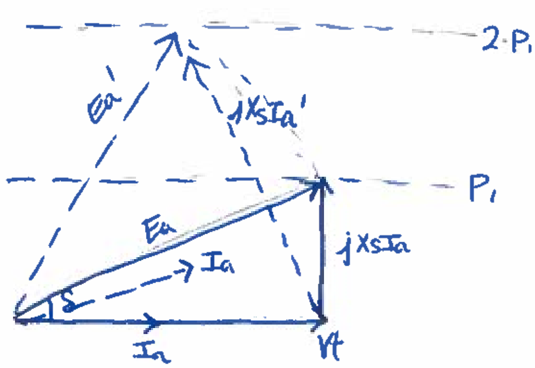
(a) Given above is a per phase equivalent circuit of a synchronous generator operating at unity power factor. Assume $R_s \rightarrow 0$.

i. Draw a corresponding phasor diagram and appropriate labels, including torque angle and the constant power line.

ii. Superimpose a modified phasor diagram if the torque of the prime mover is now doubled while field current is kept constant. Is the power factor lagging/leading?

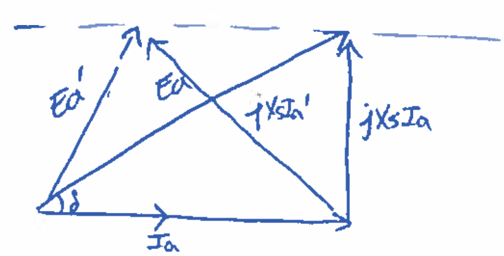
iii. Redraw the phasor diagram from part a, then superimpose a modified phasor diagram that shows what happens when field current is halved.

ii)



Power factor Leading

iii)

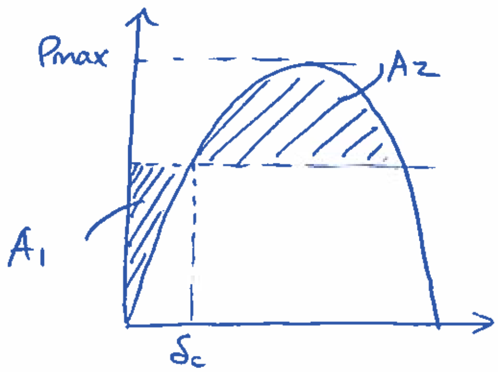


$E_a' = \frac{E_a}{2}$

10 pts

(b) The maximum sudden load torque a certain synchronous motor can accommodate corresponds to $\delta = 46.4°$. How does this "maximum sudden load" torque angle change for a machine with twice the maximum power? Explain.

The angle stays the same. P_{max} is "cancelled" out of the integral term for equal area criterion calculation

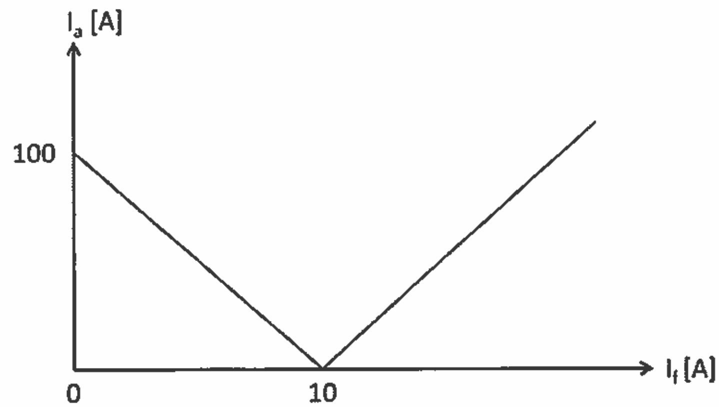


For $A_1 = A_2$, $\int_0^{\delta_c} [P_{max}\sin(\delta_c) - P_{max}\sin(\delta)]\,d\delta = \int_{\delta_c}^{\pi-\delta_c} [P_{max}\sin(\delta) - P_{max}\sin(\delta_c)]\,d\delta$

20 pts

Question 3.

(a) A 4160 V (line-line), 60Hz, 2-pole, 3-phase synchronous motor has the no-load V-curve as shown below.



Find the equivalent circuit parameters (K_f and X_s)

- $I_a = 0$, $I_f = 10$

$$K_f \omega I_f = \frac{4160}{\sqrt{3}} \Rightarrow K_f \omega = 240.18\,\Omega \Rightarrow \boxed{K_f = 0.637\ H}$$

- $I_a = 100$, $I_f = 0$

$$I_a = \frac{4160/\sqrt{3}}{X_s} \Rightarrow \boxed{X_s = 2.4\,\Omega}$$

20 pts

(b) A 45-kVA, three-phase, Y-connected, 220V (line-line), 6-pole, 60Hz synchronous machine has following test open circuit characteristic and short circuit characteristic:

OCC:

Field Current = 2.84A	Line-to-line voltage = 220V

SCC:

Field Current = 2.20A	Armature Current = 118A
Field Current = 2.84A	Armature Current = 152A

i. What would be the open circuit voltage if a prime mover spins the synchronous machine at 1600 RPM?

ii. Find the synchronous reactance in per unit and ohms.

i. $N_s = \frac{120 \cdot 60}{6} = 1200 RPM$

@ 1600RPM, $V_{open} = 220V \times \frac{1600}{1200} = \boxed{293.3 V_{\ell\text{-}\ell}}$

ii. $I_{FNL} = 2.84A$.

I_{FSC} is denoted at $I_{rated} = \frac{45 kVA}{\sqrt{3} \cdot V_{\ell\ell}} = 118 A$

$I_{FSC} = 2.2A$.

$X_{s,pu} = \frac{I_{FSC}}{I_{FNL}} = \boxed{0.775 \text{ pu}}$

$X_{s,\Omega} = 0.775 \cdot Z_{base} = 0.775 \left(\frac{V_{base}}{I_{base}} \right) = 0.775 \left(\frac{220/\sqrt{3}}{118} \right)$

$= \boxed{0.834 \Omega}$