ECE 330: Power Circuits and Electromechanics

Lecture 26

2019-12-06

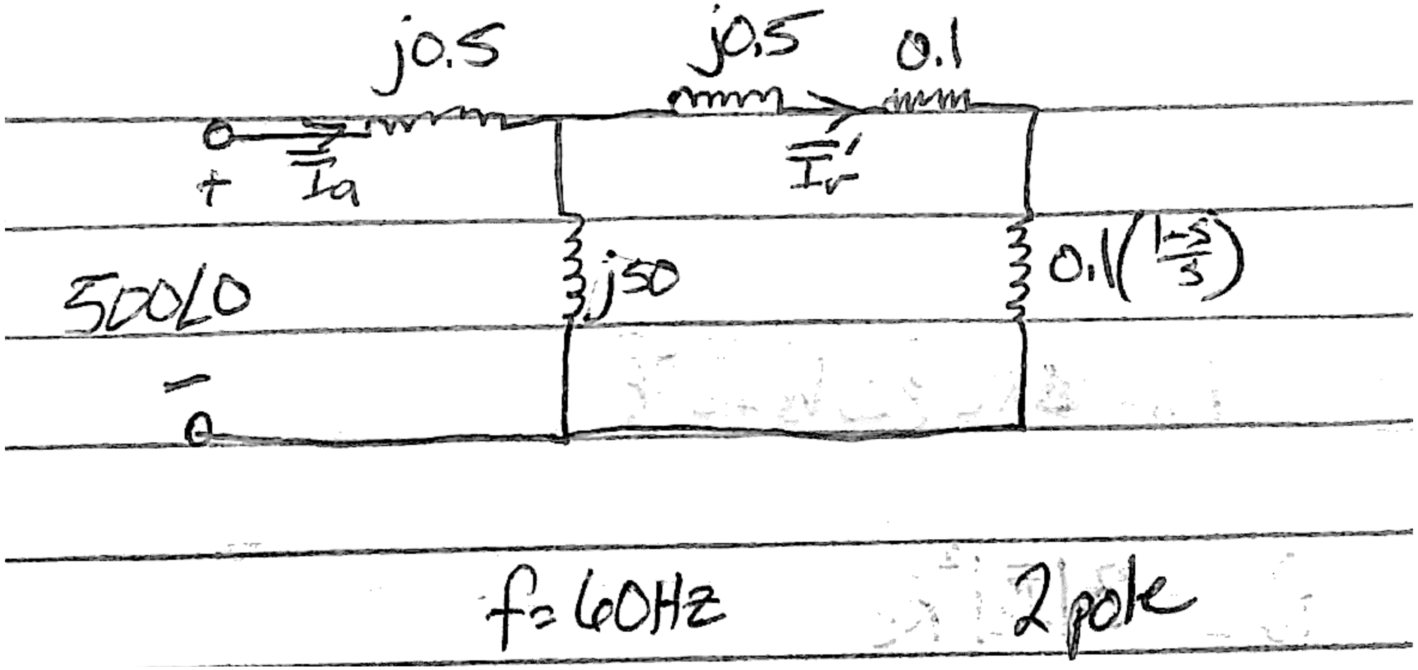
Last Time

- Induction Machines
- Equivalent Circuit

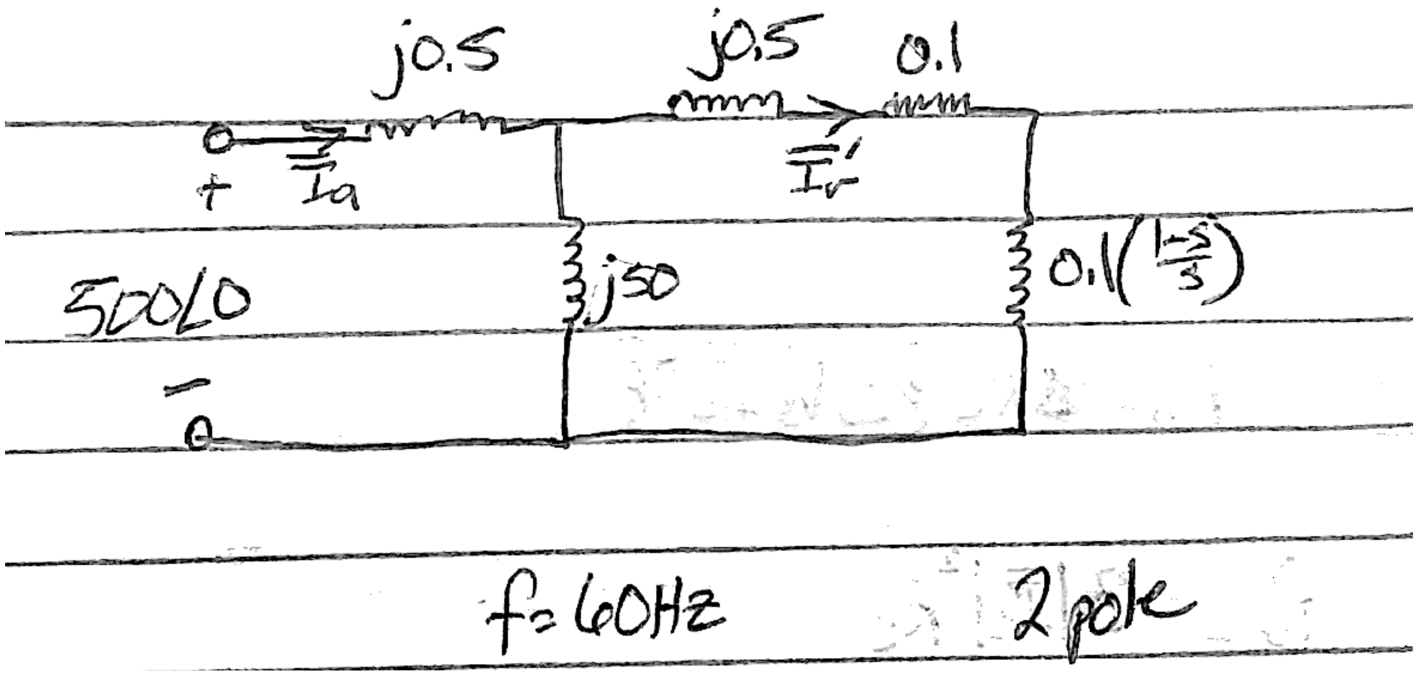
Today

- Torque vs. Slip
- Examples

Example: Torque vs. Slip



Example: Torque vs. Slip



$$T^e = \frac{P_{ag}}{\omega_s\left(\frac{2}{p}\right)}$$

$$P_{ag} = 3\left|\overline{I_r'}\right|^2\left(\frac{R_r'}{s}\right)$$

$$\overline{I_r'} = \overline{I_a} - \overline{I_m}$$

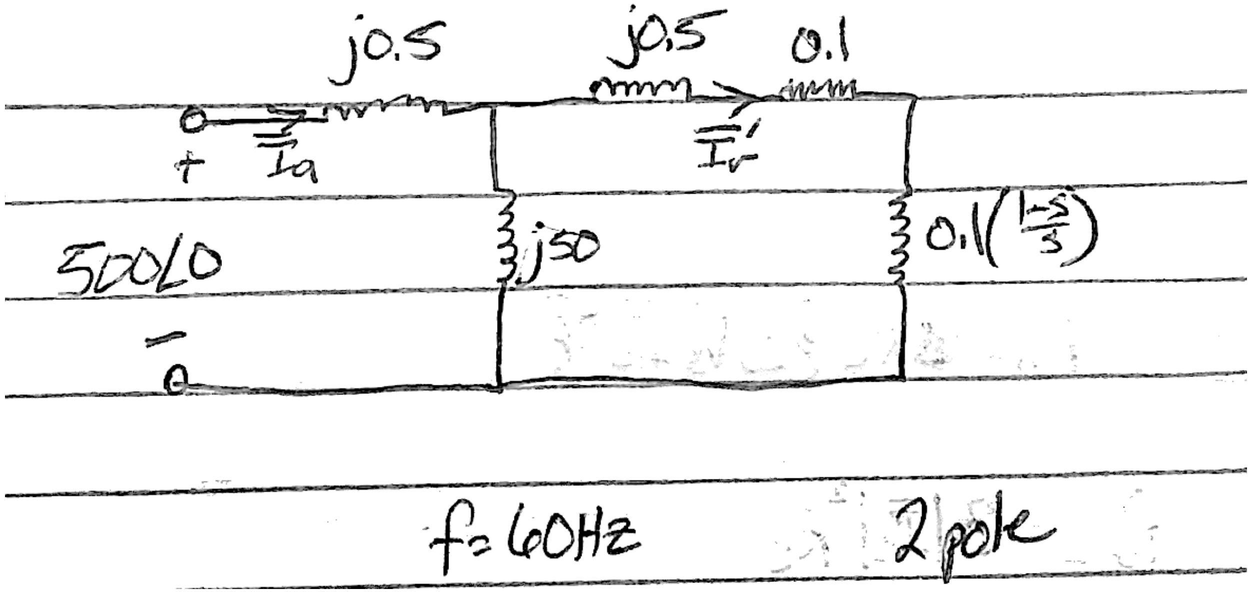
$$\overline{I_m} = \frac{\overline{V_{an}} - j0.5\overline{I_a}}{j50}$$

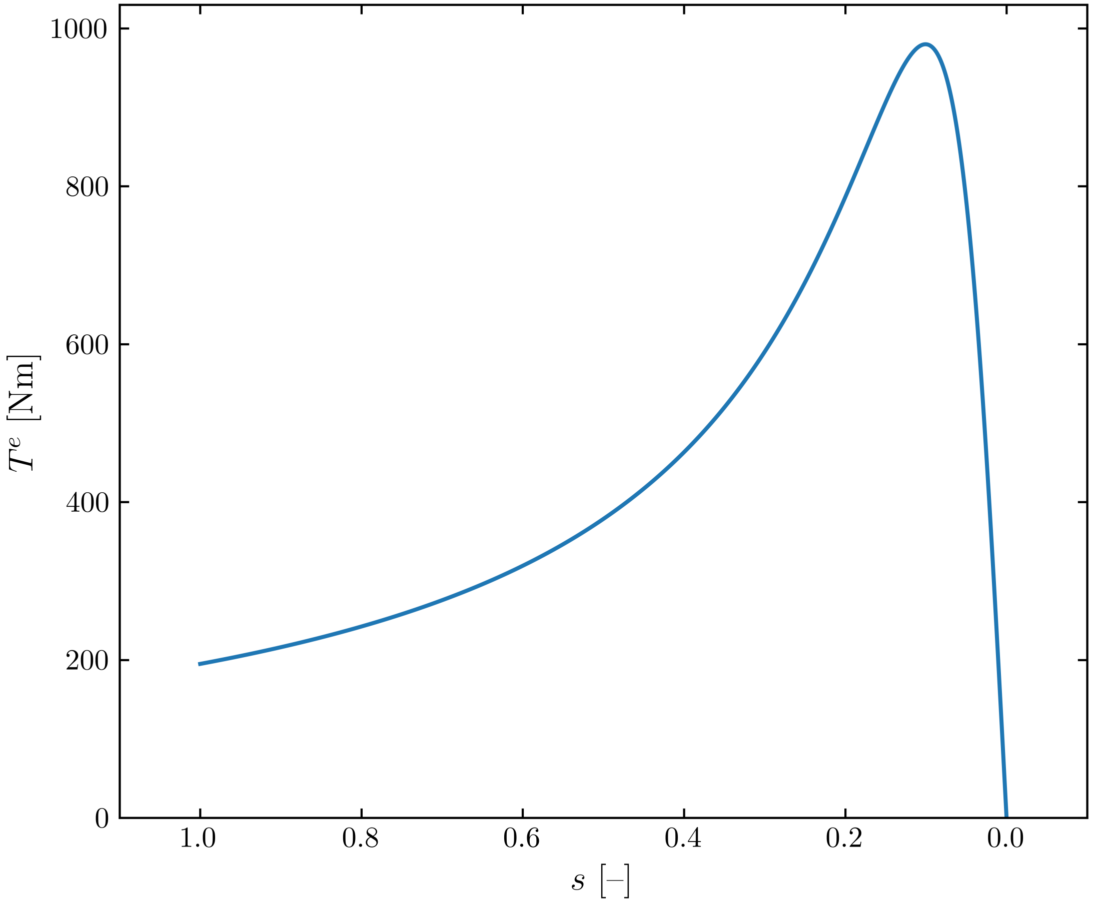
$$\overline{I_a} = \frac{\overline{V_{an}}}{\overline{Z_{tot}}}$$

$$\overline{Z_{tot}} = j0.5 + \left(\frac{1}{j50} + \frac{1}{\frac{0.1}{s} + j0.5}\right)^{-1}$$

The torque will vary with *s*

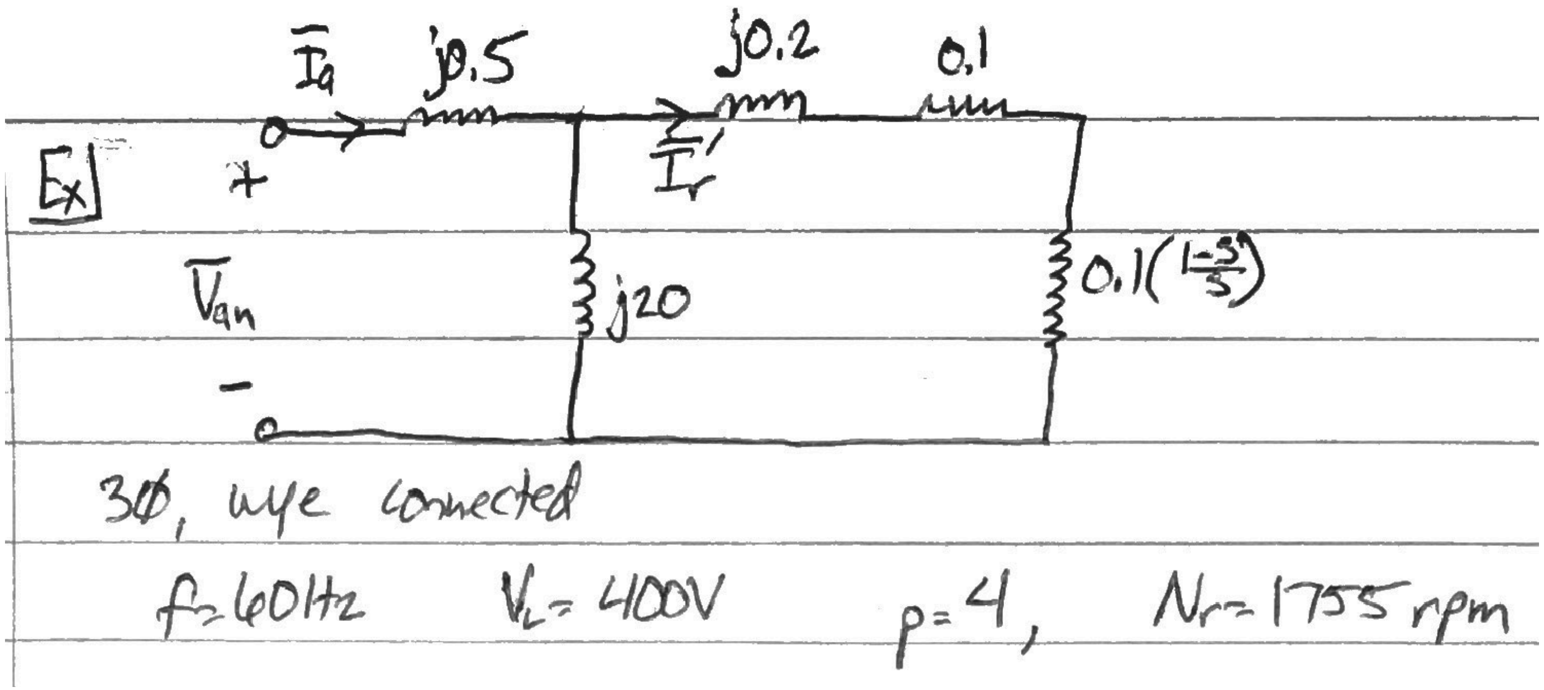
Example: Torque vs. Slip





When s=0, $T^e = 0$
Maximum is T^e
Decays with increase s after reaching max

Example



What is the torque?

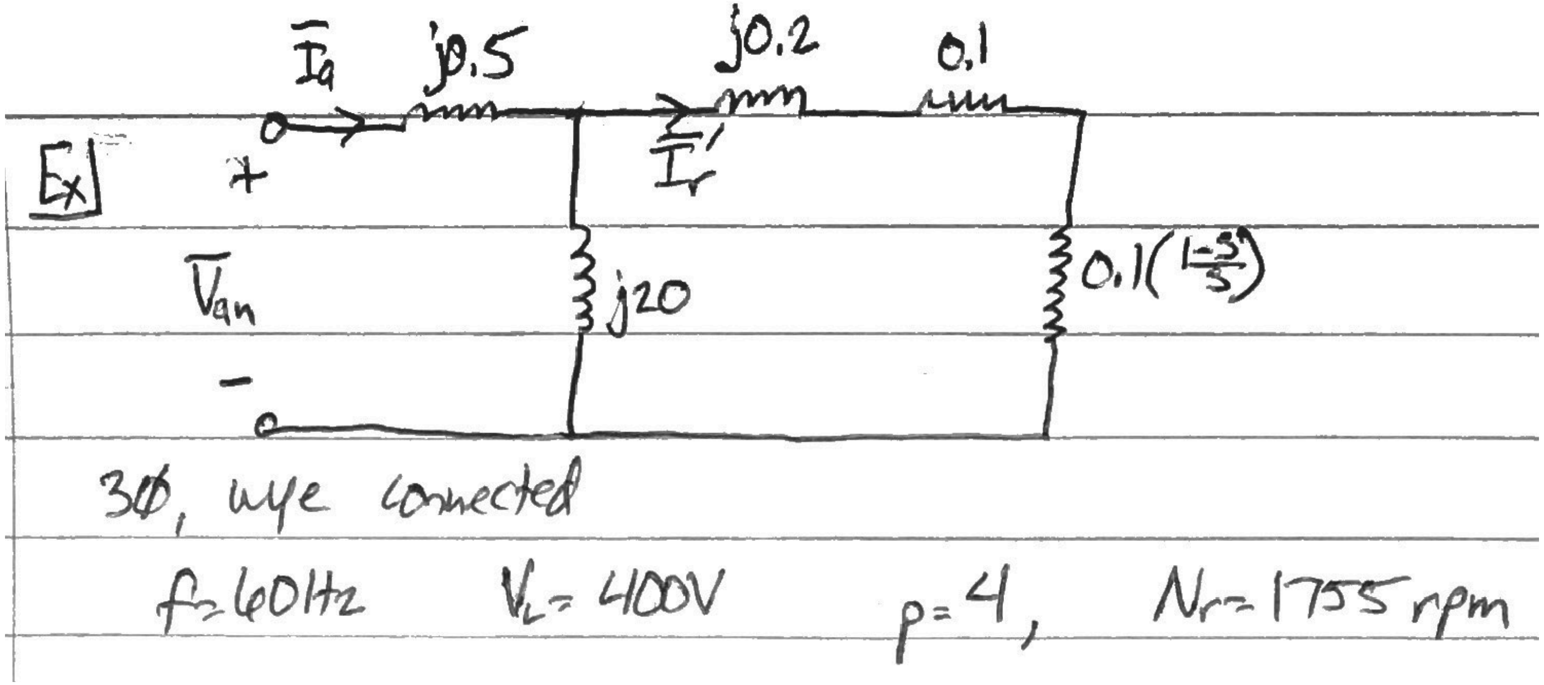
a) 98.09 Nm

b) 1232.6 Nm

c) 196.18 Nm

d) 21.07 Nm

Example



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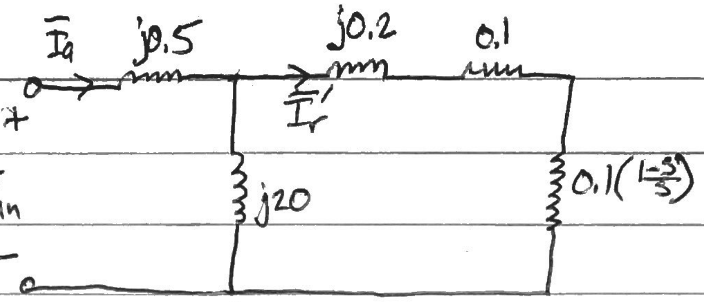
Ex



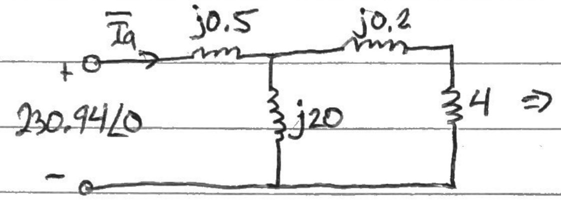
3Ø, wye connected

$f = 60\,Hz$ $V_L = 400\,V$ $p = 4$, $N_r = 1755\,rpm$

Find: T^e

Solution: $N_s = \left(\frac{2}{4}\right) 2\pi(60)\left(\frac{60}{2\pi}\right) \Rightarrow N_s = 1800\,rpm$

$s = \frac{N_s - N_r}{N_s} \Rightarrow s = \frac{1800 - 1755}{1800} \Rightarrow \boxed{s = 0.025}$



$\Rightarrow \bar{I}_a = \frac{\bar{V}_{an}}{Z_{eq}} \Rightarrow \bar{I}_a = \frac{230.94\angle 0}{4.041\angle 20.958^\circ}$

$\boxed{\bar{I}_a = 57.149\angle -20.958^\circ}$

$\bar{I}_r' = \frac{230.94\angle 0 - j0.5\bar{I}_a}{4 + j0.2} \Rightarrow$

$\bar{I}_r' = \frac{222.237\angle -6.893^\circ}{4 + j0.2} \Rightarrow \bar{I}_r' = 55.512\angle -9.756^\circ$

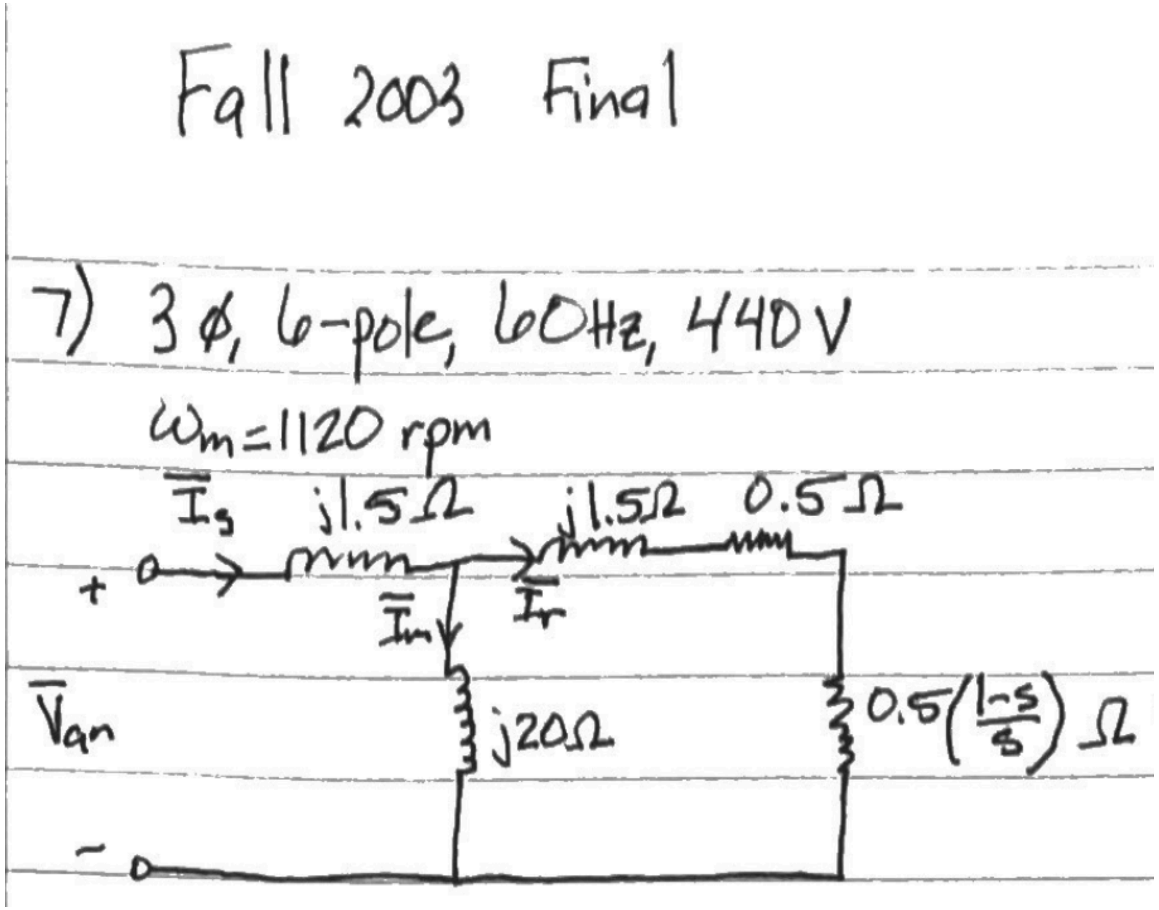
$P_{AG} = 3(55.512)^2(4) \Rightarrow P_{AG} = 36.978\,kW$

$T^e = \frac{P_{AG}}{\frac{2}{p}\omega_s} \Rightarrow T^e = \frac{36.978\,kW}{\left(\frac{2}{4}\right)(2\pi 60)} \Rightarrow \boxed{T^e = 196.18\,Nm}$

What does “starting” mean?

- Calculate torque at motor starting
- At starting, motor is just about to move, but hasn’t started moving yet $\omega_m = 0, s = 1$
- The $R_r'\left(\frac{1-s}{s}\right)$ term in circuit becomes a short
- Evaluate the circuit as usual to find the torque

Example



What is the current drawn by the system at start?

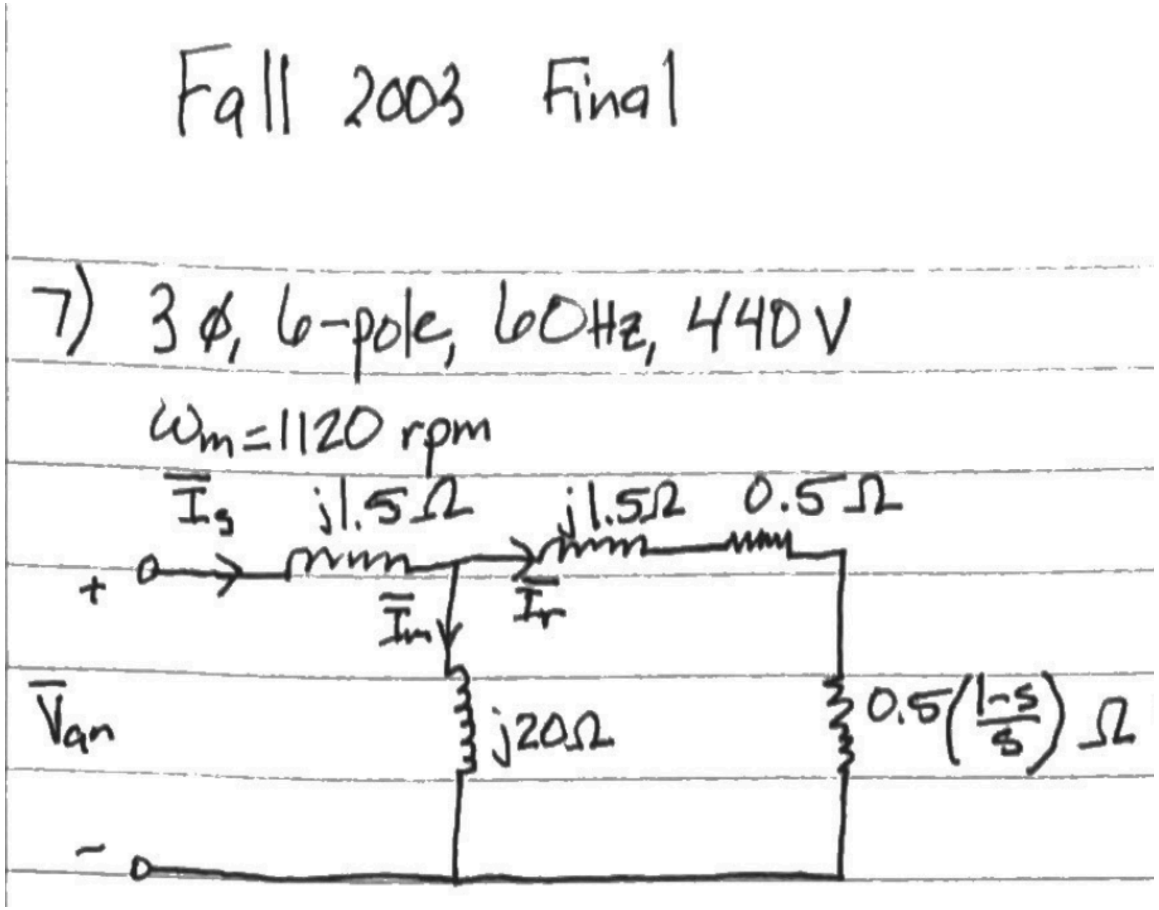
a) $149.81\angle - 81.54°$ A

b) $86.49\angle - 81.54°$ A

c) $11.82\angle - 90°$ A

d) $100\angle - 81.54°$ A

Example



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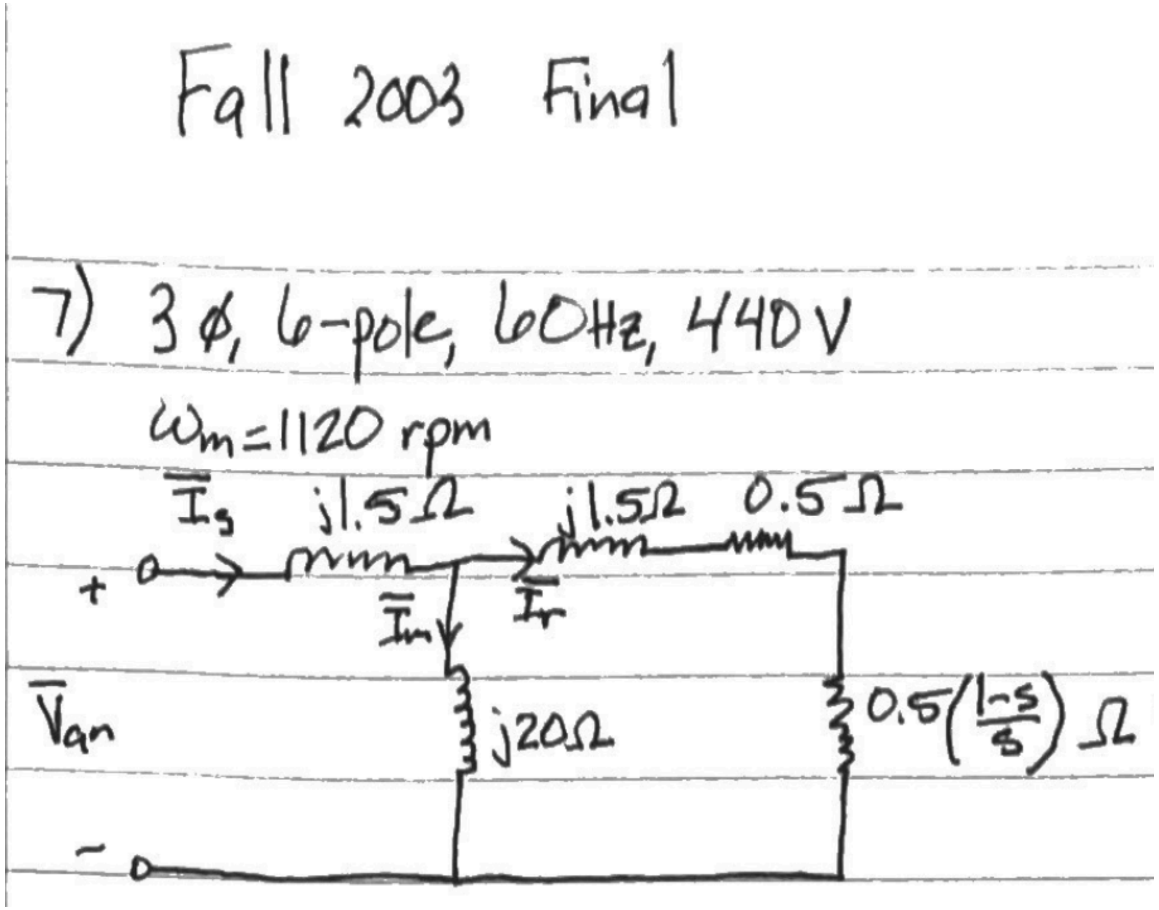


What is the starting torque?

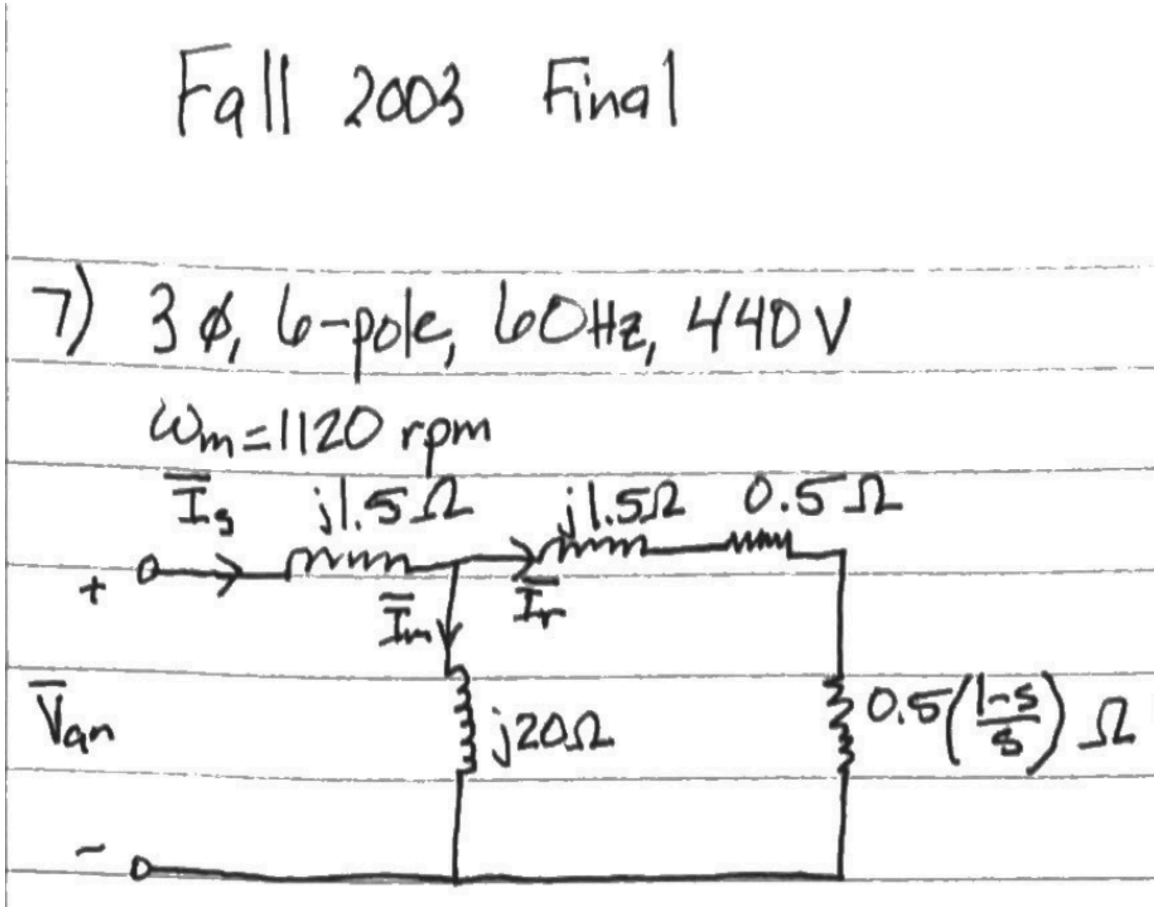
a) 29.76 Nm

b) 9.92 Nm

c) 187.0 Nm

d) 89.3 Nm

Example



What is the starting torque?

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b) 9.92 Nm

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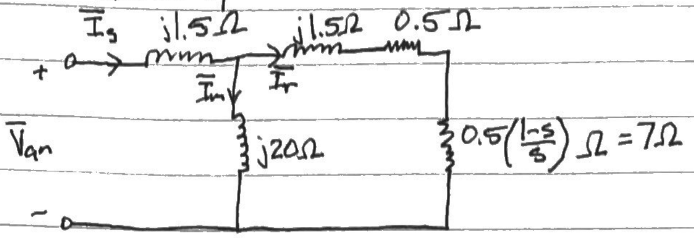
Fall 2003 Final

7) 3 ϕ, 6-pole, 60Hz, 440V

$\omega_m = 1120$ rpm



a) $s = \frac{\omega_s - \left(\frac{P}{2}\right)\omega_m}{\omega_s} = \frac{3600 - \left(\frac{6}{2}\right)(1120)}{3600} \Rightarrow s = 0.0667$

$f_r = sf_s \Rightarrow f_r = 0.0667(60) \Rightarrow \boxed{f_r = 4 \text{ Hz}}$

b) $\bar{Z}_{eq} = j1.5 + \left(\frac{1}{7.5+j1.5} + \frac{1}{j20}\right)^{-1} \Rightarrow \bar{Z}_{eq} = 5.786 + j4.914\ \Omega$
$= 7.591\angle 40.34°\ \Omega$

$\bar{I}_s = \frac{\bar{V}_{an}}{\bar{Z}_{eq}} \Rightarrow \bar{I}_s = \frac{\frac{440}{\sqrt{3}}\angle 0°}{7.591\angle 40.34°} \Rightarrow \boxed{\bar{I}_s = 33.465\angle -40.34° A}$

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

$\bar{I}_r = \frac{\bar{V}_{an} - j1.5\bar{I}_s}{7.5+j1.5} \Rightarrow \bar{I}_r = \frac{\frac{440}{\sqrt{3}}\angle 0° - 50.198\angle 49.66°}{7.5+j1.5} \Rightarrow \bar{I}_r = \frac{221.540 - j38.262}{7.5+j1.5}$

$\bar{I}_r = 27.421 - j10.586 \Rightarrow \bar{I}_r = 29.393\angle -21.11°$

$P_{AG} = 3|\bar{I}_r|^2\left(\frac{R_r'}{s}\right) \Rightarrow P_{AG} = 3(29.393)^2(7.5) \Rightarrow P_{AG} = 19{,}438.84\,W$

$T^e = \frac{P_{AG}}{\left(\frac{2}{P}\right)\omega_s} \Rightarrow \boxed{T^e = 154.69\ Nm}$

d) at start, s=1, $\bar{Z}_{eq} = j1.5 + \left(\frac{1}{0.5+j1.5} + \frac{1}{j20}\right)^{-1} \Rightarrow \bar{Z}_{eq} = 2.937\angle 81.54°$

$\bar{I}_s = \frac{\bar{V}_{an}}{\bar{Z}_{eq}} \Rightarrow \boxed{\bar{I}_s = 86.49\angle -81.54° A}$