

ECE3600 Final given: Spring 25

Closed book, Closed notes, Calculator OK, Do Not use Eraseable Ink

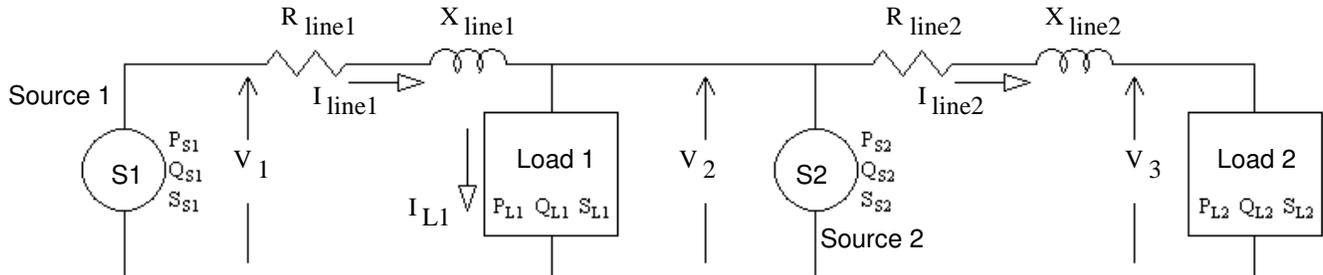
Write Legibly!

A wrong answer may cost more than what a right answer is worth, so don't just guess.

(86 pts) Questions

Answers left blank cost the same as the right answer was worth.

1. Consider the single-phase system below. There are two sources, labeled S1 and S2 and two loads, labeled L1 and L2. All the variables shown or referred to in the questions are scalar or magnitudes of complex numbers. The same should be true of your answers.



- Example) Is there a simple relationship between all the real powers above? If yes, express that relationship in a mathematical way using items labeled above.

NO YES

$$P_{S1} + P_{S2} = I_{line1}^2 \cdot R_{line1} + I_{line2}^2 \cdot R_{line2} + P_{L1} + P_{L2}$$

Note: You are not being asked for FORMULAs. You are being asked to express basic concepts in a mathematical way.

- a) Is there a simple relationship between all the reactive powers above? NO YES
If yes, express that relationship in a mathematical way.

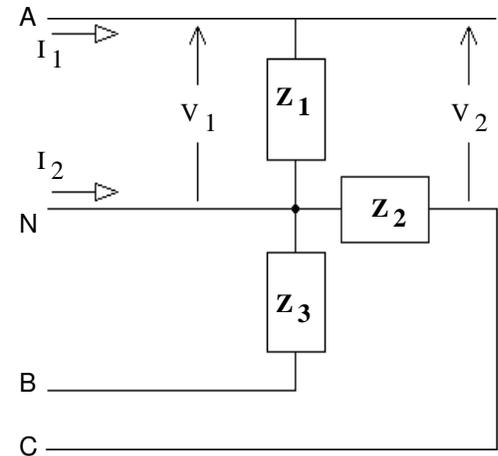
- b) Is there a simple relationship between all the apparent powers above? NO YES
If yes, express that relationship in a mathematical way.

- c) Is there a simple relationship between all the power factors above? NO YES
If yes, express that relationship in a mathematical way.

- d) Express V_2 in terms of any items shown to the right of where V_2 is shown on the drawing.

- e) Express the efficiency in terms of real and/or reactive powers.

2. Consider the balanced three-phase load shown. Except for the Z 's, all the variables shown or referred to in the questions are scalar or magnitudes of complex numbers. The same should be true of your answers. Where possible, express answers mathematically. You may use the functions $\text{Re}(\)$, $\text{Im}(\)$ and \angle and trig functions.



a) What is the value V_2 ? (may be expressed in terms of V_1)

b) What is the value I_2 ? (may be expressed in terms of I_1)

c) Is one of the voltages shown also known as the line voltage? If yes, which one? NO YES

d) Is one of the currents shown also known as the line current? If yes, which one? NO YES

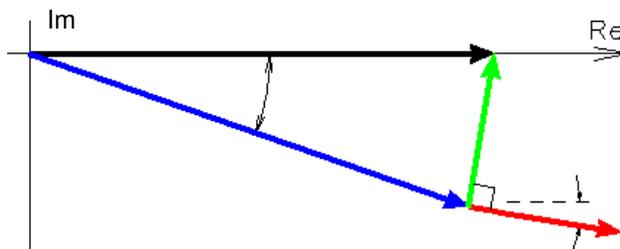
e) Could we find an equivalent load connected the other way (Δ if now Y, or Y if now Δ)? If yes what Z values should be used? Finish one of these two expressions: NO YES

f) Express the real power used by this load.

g) Express the reactive power used by this load.

3. The following questions pertain to a 3-phase synchronous machine.

a) Label all the phasors and angles shown.

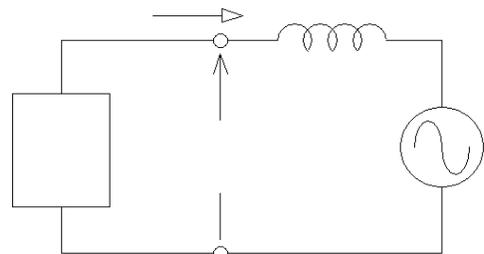


b) Is this phasor diagram for a motor or a generator?

c) Judging by the phasor diagram, is the machine using + or - reactive power?

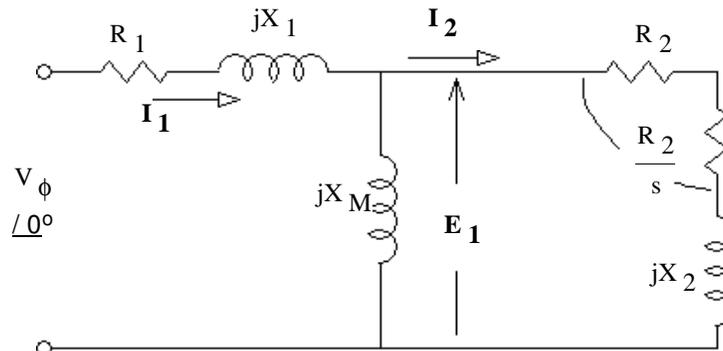
d) Label the diagram with the voltage and current labels used in a). Also label anything else of importance.

e) Express the relationship between the 3 voltage phasors above (they can be complex numbers).



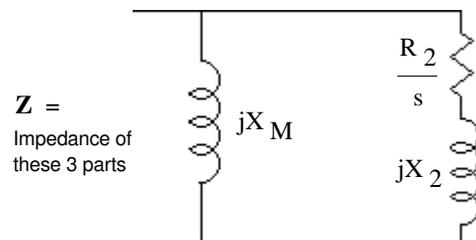
5. a) Draw the basic electrical schematic of the armature of a brushed DC motor in the space at right and label your drawing.
- b) Express the most basic relationship between the items you just labeled on your drawing.
- c) Express the relationship between the induced torque and one or more of the electrical values on your drawing.
- d) Express the relationship between the motor speed and one or more of the electrical values on your drawing.
- e) Express the power converted to mechanical power in terms given or found above. Give two expressions
- f) Express the output shaft power in mechanical terms.
- g) The magnetic flux of one type of DC motor can be easily changed, what type is that?
- h) If the magnetic flux is reduced in a lightly-loaded motor, what bad thing can happen?

6. The following questions pertain to a 3-phase induction motor. A model of one phase is shown. Bold variables are complex, all others are scalar.



a) What is the variable "s" called?

b) A partial schematic is shown at right. Find (write) an expression for the combined impedance, **Z**.



c) Write an expression for **E₁** in terms of **V_φ** and the impedances given or found above.

d) Write an expression for $|I_2|$ in terms of E_1 and the impedances given or found above.

e) Express the stator-copper-loss of this 3 ϕ motor in terms given or found above.

f) Express the rotor-copper-loss in terms given or found above.

g) Express the air-gap power in terms given or found above.

h) Express the power converted to mechanical power in terms given or found above.

7. What type of problem does a differential relay detect?

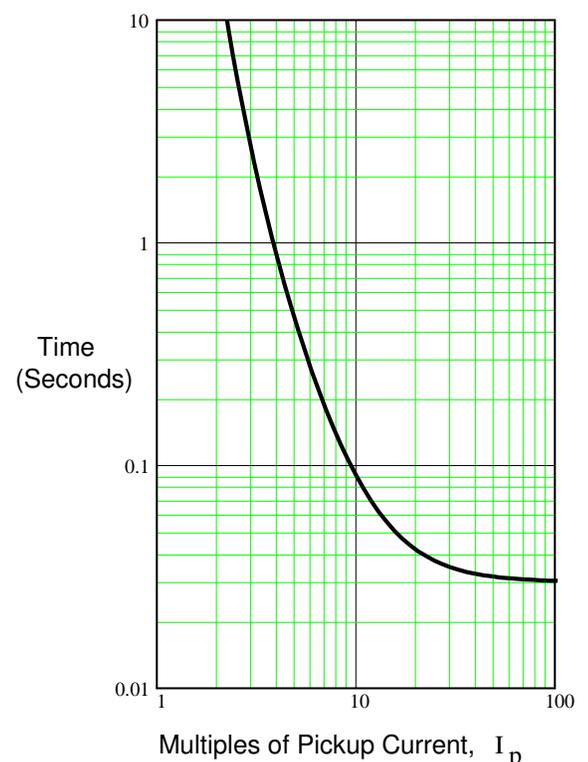
8. What type of problem does a pilot relay detect?

9. The time-delay curve of an over-current relay is shown.

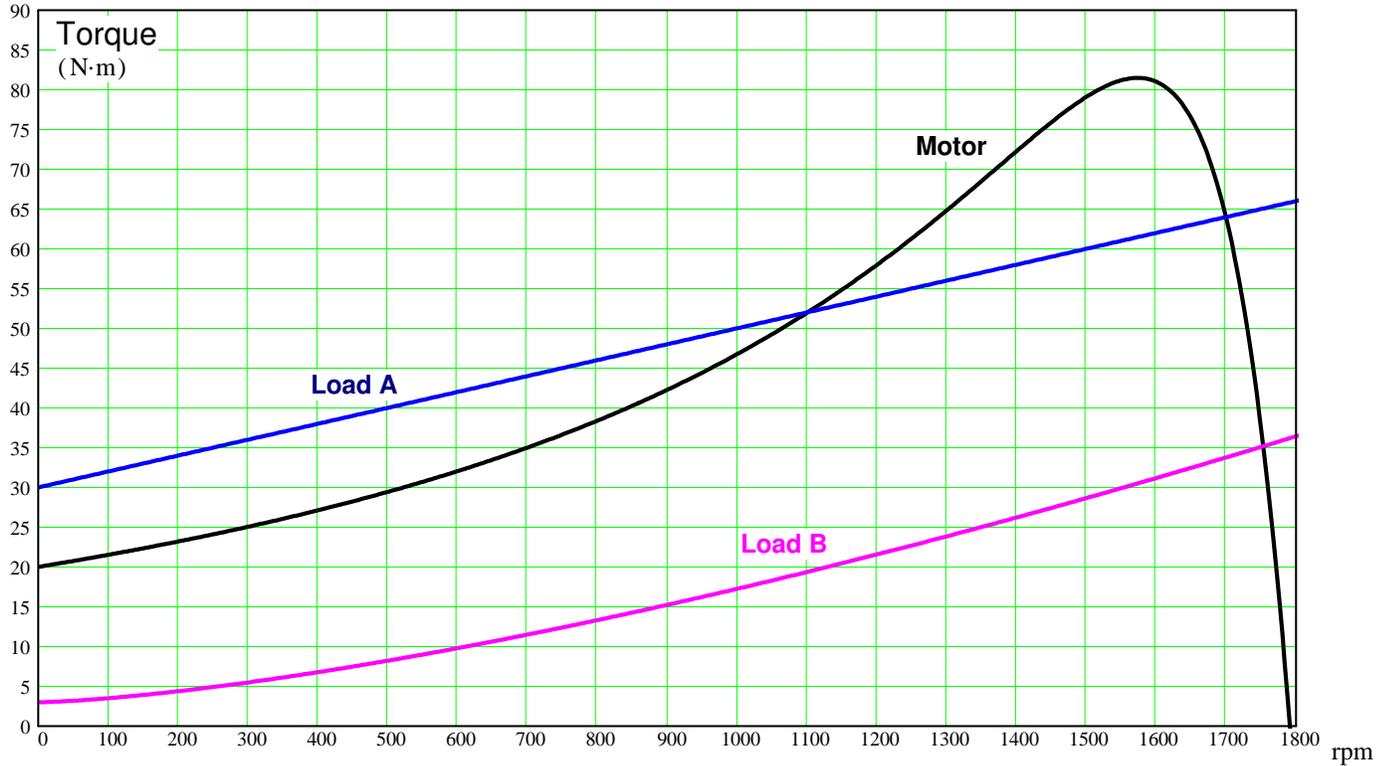
a) How long will it take to trip the breaker if the current is 3 times the pickup current?

b) How long will it take to trip the breaker if the current is 10 times the pickup current?

c) What is the quickest this relay will trip the breaker?



1. (12 pts) Three torque-speed curves are shown below. One is for a motor and the other two are for two different loads that could be attached to this motor. Most of your answers to the questions below will be approximate.



- a) What kind of motor is it? Also state the number of poles, if applicable.
- b) The motor is allowed to start with no load attached. After it has reached its no-load speed, load A is attached. At what steady-state speed will the motor run?
- c) If load A is attached to the motor *before* the motor is powered on, at what speed will the motor run after it's powered on and allowed to reach steady-state?
- d) The motor is turned off and load B is attached to the motor instead of load A. The motor is then powered on. At some instant during start-up the motor and load will be spinning at 600 rpm. What is the difference between the motor torque and the load torque at that speed?
- e) How can the two torques be unequal? What is that torque differential doing?
- f) With load B attached to the motor, at what speed will the motor eventually run?

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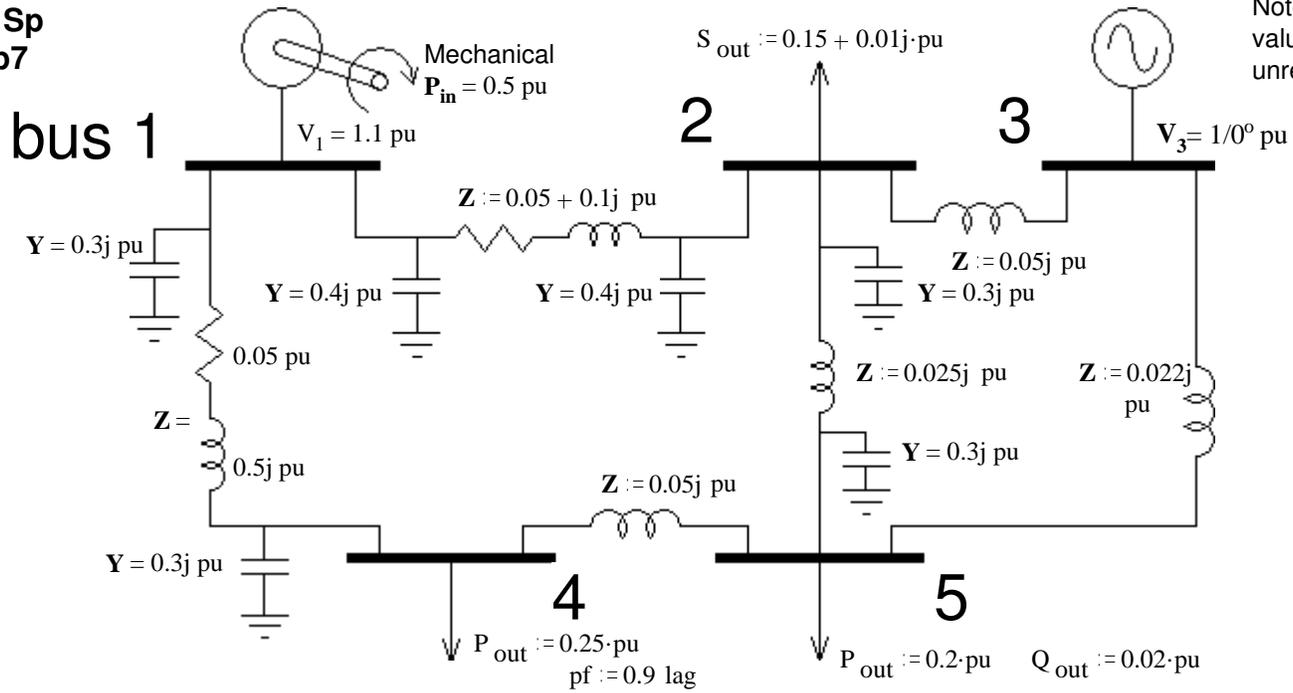
2. (20 pts) Consider the small power system shown on the next page. values shown are per-unit.

a) Identify each bus as "slack", "load", or "generator".

bus 1. _____ 2. _____ 3. _____ 4. _____ 5. _____

b) Show V_1 , V_2 , V_4 and V_5 on the drawing (as letters, not values).

c) Show I_1 , I_2 , I_3 , I_4 and I_5 on the drawing and draw arrows to indicate the direction of each. **ECE 3600 Fin Sp 25 p6**



d) What is the 5x5 matrix shown below called? _____

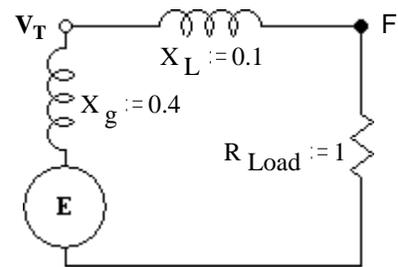
$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{bmatrix} = \begin{bmatrix} \mathbf{A} & \mathbf{B} & _ & _ & _ \\ _ & _ & _ & _ & _ \\ _ & _ & _ & _ & _ \\ _ & _ & _ & _ & _ \\ _ & _ & _ & _ & _ \end{bmatrix} \cdot \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \end{bmatrix}$$

e) A number of the elements of the matrix are zero (0).
Fill in all the zero elements.

f) Find elements **A** and **B** in the matrix above. I want numerical answers accurate to at least ± 0.01 pu.

3. (40 pts) One phase of a balanced 3-phase system is shown here.
 E and X_g represent a synchronous generator.

a) $E := 1.1 \text{ pu}$ $X''_{g1} := 0.1$ Find E''



ALL values are pu.

**Fin Sp
25 p8**

b) A fault occurs at point F. Lines B and C are **both** dead shorted to ground.

Draw the circuit you will have to analyze and find the voltage, V_{A1} , and the currents, I_{A1} , I_{A2} and I_{A0} .

c) Set up a mathematical expression (or expressions) to find the voltage, V_{A1} , and the currents, I_{A1} , I_{A2} and I_{A0} .

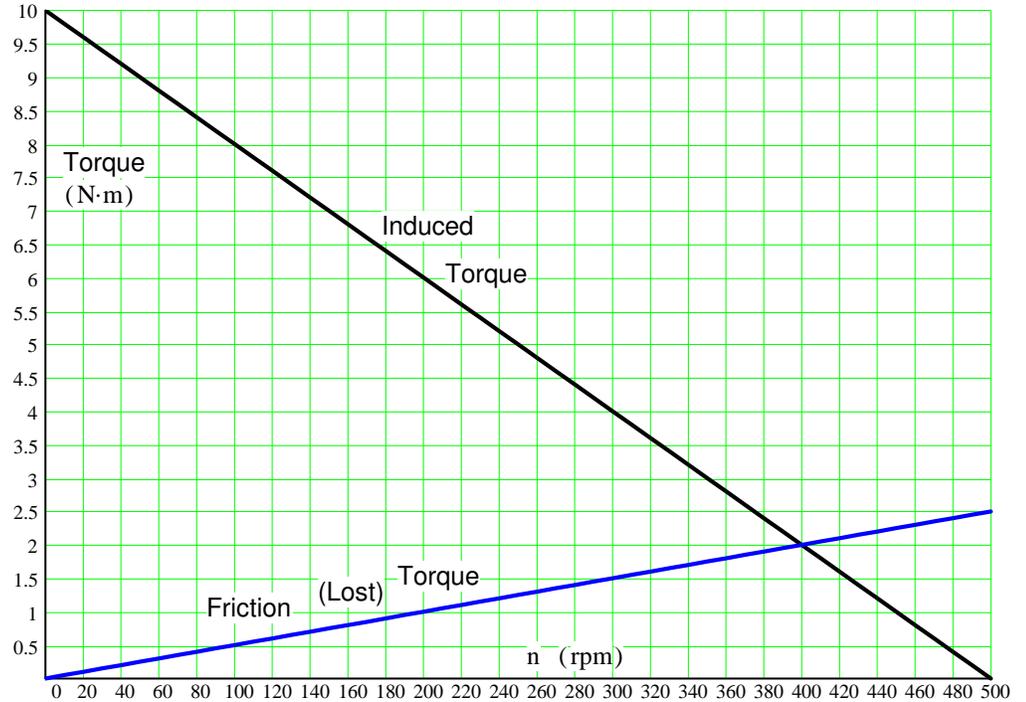
d) After lots of complex arithmetic, \mathbf{V}_{A1} , \mathbf{I}_{A1} , \mathbf{I}_{A2} and \mathbf{I}_{A0} are found to be: $\mathbf{V}_{A1} := 0.4 \cdot e^{-j \cdot 25 \cdot \text{deg}}$ $\mathbf{V}_{A1} = 0.363 - 0.169j$
 $\mathbf{I}_{A1} := -1 - 4 \cdot j = 4.12311 / \underline{-104.036^\circ}$ $\mathbf{I}_{A2} := 0.75 + 2.5 \cdot j = 2.61008 / \underline{73.301^\circ}$ $\mathbf{I}_{A0} := 0.25 + 1.5 \cdot j = 1.52069 / \underline{80.538^\circ}$

Find the fault voltage, \mathbf{V}_A and the fault currents, \mathbf{I}_B and \mathbf{I}_C , as complex pu values.

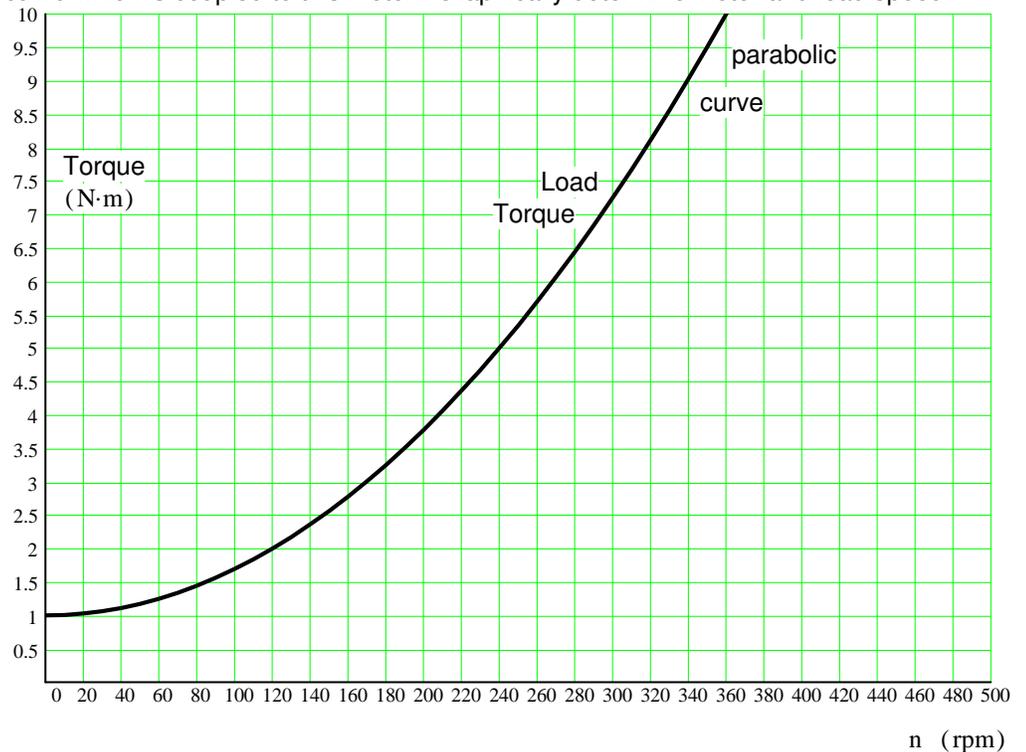
$$\mathbf{a} := 1 \cdot e^{j \cdot 120 \cdot \text{deg}}$$

4. (22 pts) The torque-speed characteristics of a permanent-magnet DC motor are shown below. The top line is the induced torque. The lower line is torque lost to friction inside the motor.

Notes: I intend for you to solve this graphically, so answers won't be perfect. Rulers are available from Arn. Add extra lines and show operating points. You may solve this algebraically, if you wish.
a) Find the no-load speed.



b) The curve below shows a load curve which is coupled to this motor. Graphically determine motor and load speed.



For parts c) and d) The terminal voltage of the motor is reduced by half.

c) Find the new no-load speed,

d) Graphically determine the new motor speed when coupled to the load of part b).

Also show the operating points for parts b) and d) on the curve above.

Answers

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1. a) YES $Q_{S1} + Q_{S2} = I_{line1}^2 \cdot X_{line1} + I_{line2}^2 \cdot X_{line2} + Q_{L1} + Q_{L2}$

b) NO c) NO

d)
$$V_2 = \frac{\sqrt{(I_{line2}^2 \cdot R_{line2} - P_{L2})^2 + (I_{line2}^2 \cdot X_{line2} - Q_{L2})^2}}{I_{line2}}$$

e)
$$\eta = \frac{P_{L1} + P_{L2}}{P_{S1} + P_{S2}}$$

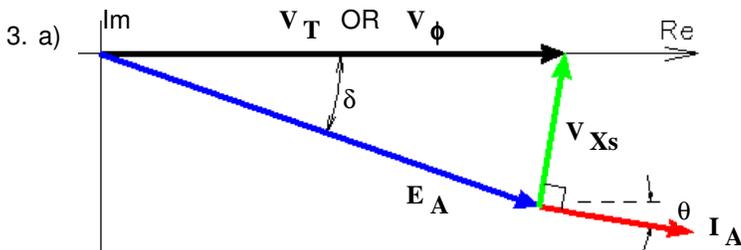
2. a) $V_2 = \sqrt{3} \cdot V_1$ b) $I_2 = 0$ c) YES V_2 d) YES I_1

$$= \frac{P_{L1} + P_{L2}}{P_{L1} + P_{L2} + I_{line1}^2 \cdot R_{line1} + I_{line2}^2 \cdot R_{line2}}$$

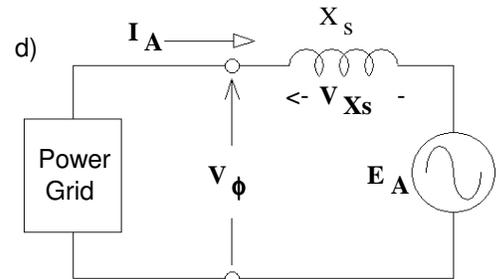
$$= \frac{P_{S1} + P_{S2} - (I_{line1}^2 \cdot R_{line1} + I_{line2}^2 \cdot R_{line2})}{P_{S1} + P_{S2}}$$

e) YES $Z_{\Delta} = 3 \cdot Z_Y$ OR $3 \cdot Z_1$ either answer $Z_Y = \frac{Z_{\Delta}}{3}$

f) $3 \cdot I_1^2 \cdot \text{Re}(Z_1)$ g) $3 \cdot I_1^2 \cdot \text{Im}(Z_1)$



b) motor
c) positive +



e) $V_{\phi} = E_A + V_{Xs} = E_A + I_A \cdot j \cdot X_s$ OR $E_A = V_{\phi} - V_{Xs} = V_{\phi} - I_A \cdot j \cdot X_s$

4. a) Ideal transformer b) $\frac{I_2}{I_1} = \frac{N_1}{N_2}$ c) YES $R_{eq} = R_L \cdot \left(\frac{N_1}{N_2}\right)^2$ $X_{eq} = X_L \cdot \left(\frac{N_1}{N_2}\right)^2$

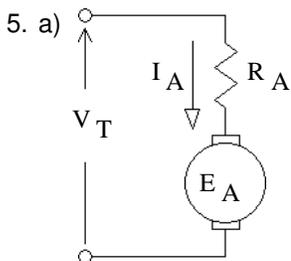
d)
$$I_1 = \frac{V_p}{\sqrt{\left[R_s + R_L \cdot \left(\frac{N_1}{N_2}\right)^2\right]^2 + \left[X_s + X_L \cdot \left(\frac{N_1}{N_2}\right)^2\right]^2}}$$
 OR
$$I_1 = \frac{V_p}{\sqrt{(R_s + R_{eq})^2 + (X_s + X_{eq})^2}}$$

e) $P_S = \frac{V_p^2}{R_m} + I_1^2 \cdot (R_s + R_{eq})$

f) $Q_S = \frac{V_p^2}{X_m} + I_1^2 \cdot (X_s + X_{eq})$

h) $I_p = \frac{\sqrt{P_S^2 + Q_S^2}}{V_p}$

i) $\eta = \frac{I_1^2 \cdot R_{eq}}{P_S}$



b) $V_T = I_A \cdot R_A + E_A$ c) $\tau_{ind} = K_T \cdot \phi \cdot I_A$

d) $E_A = K_V \cdot \phi \cdot \omega$

e) $P_{conv} = E_A \cdot I_A = \tau_{ind} \cdot \omega_m$

f) $P_{out} = \tau_{shaft} \cdot \omega_m$ g) Separately excited

h) Motor speed can increase too much

6. a) The slip

c) $E_1 = V_{\phi} \cdot \frac{Z}{R_1 + j \cdot X_1 + Z}$

b)
$$Z = \frac{1}{\frac{1}{j \cdot X_m} + \frac{1}{\left(\frac{R_2}{s} + j \cdot X_2\right)}}$$

6. d)
$$|I_2| = \frac{|E_1|}{\sqrt{\left(\frac{R_2}{s}\right)^2 + X_2^2}} = \left| \frac{E_1 \text{ OR}}{\frac{R_2}{s} + j \cdot X_2} \right|$$

e) $P_{SCL} = 3 \cdot [(|I_1|)^2 \cdot R_1]$

f) $P_{RCL} = 3 \cdot [(|I_2|)^2 \cdot R_2]$

g) $P_{AG} = 3 \cdot \left[(|I_2|)^2 \cdot \frac{R_2}{s} \right]$

h) $P_{conv} = (1 - s) \cdot P_{AG}$
 $= P_{AG} - P_{RCL}$

7. Current into a device doesn't match the current out.

8. Current into a transmission line doesn't match the current out.

9. a) 3-sec b) 0.09-sec c) 0.03-sec

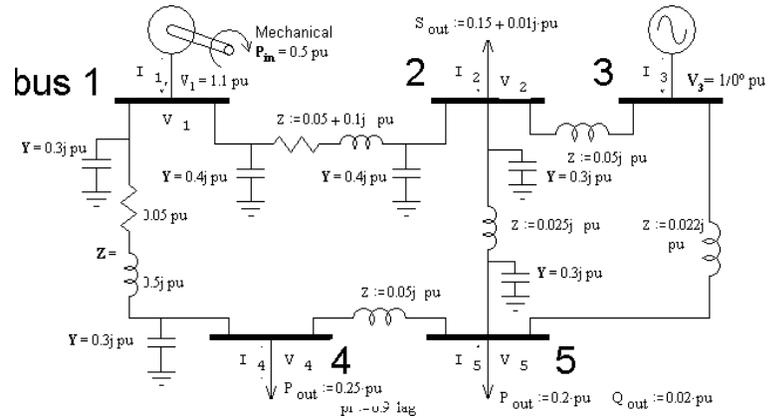
Problems

1. a) 3-phase, 4-pole induction motor b) 1700-rpm
 c) 0-rpm It will never start because the load torque at 0 rpm is higher than the starting torque. d) 22·N·m
 e) Accelerating the motor rotor and load. f) 1750-rpm approx

2. a) generator, load, slack, load, load,

b)

c)

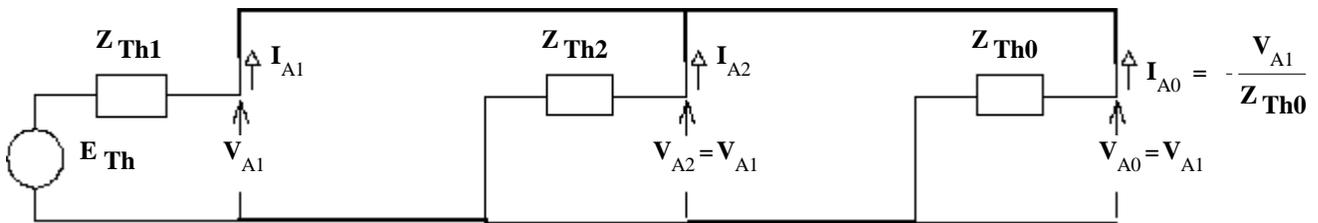


f) $B := -4 + 8 \cdot j \text{ pu}$ $A := 4.198 - 9.28 \cdot j \text{ pu}$

3. a) $0.968 - 0.264 \cdot j \text{ pu}$

$V_{A1} = V_{A2} = V_{A0}$

b)



c) $E_{Th} = E'' \cdot \frac{R_{Load1}}{(X''_{g1} + X_{L1}) \cdot j + R_{Load1}}$

$Z_{Th1} = \frac{1}{\frac{1}{(X''_{g1} + X_{L1}) \cdot j} + \frac{1}{R_{Load1}}}$

$Z_{Th2} = \frac{1}{\frac{1}{(X''_{g2} + X_{L2}) \cdot j} + \frac{1}{R_{Load2}}}$

$Z_{Th0} = \frac{1}{\frac{1}{(X''_{g0} + X_{L0}) \cdot j} + \frac{1}{R_{Load0}}}$

$I_{A1} = \frac{E_{Th}}{Z_{Th1} + \frac{1}{\frac{1}{Z_{Th2}} + \frac{1}{Z_{Th0}}}}$

$V_{A1} = I_{A1} \cdot \left(\frac{1}{\frac{1}{Z_{Th2}} + \frac{1}{Z_{Th0}}} \right)$

$I_{A2} = -\frac{V_{A1}}{Z_{Th2}}$ $I_{A0} = -\frac{V_{A1}}{Z_{Th0}}$

d) $I_B = -5.254 + 3.766 \cdot j \text{ pu}$

$I_C = 6.004 + 0.734 \cdot j \text{ pu}$

4. a) 400-rpm b) 222.5-rpm

c) 200-rpm d) 120-rpm

