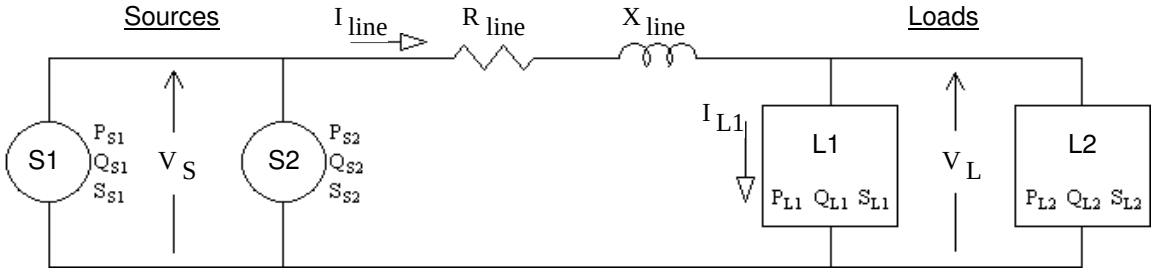
ECE3600 Final given: Spring 24

Write Legibly! Closed book, Closed notes, Calculator OK.

(95 pts) Questions A wrong answer may cost more than what a right answer is worth. Blanks cost the same as the right answer was worth, so don't just guess

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? NO (YES)
If yes, express that relationship in a mathematical way.

$P_{S1} + P_{S2} = P_{Rline} + P_{L1} + P_{L2}$ OR $P_{S1} + P_{S2} = I_{line}^2 \cdot R_{line} + P_{L1} + P_{L2}$ (Only one answer is necessary)

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.

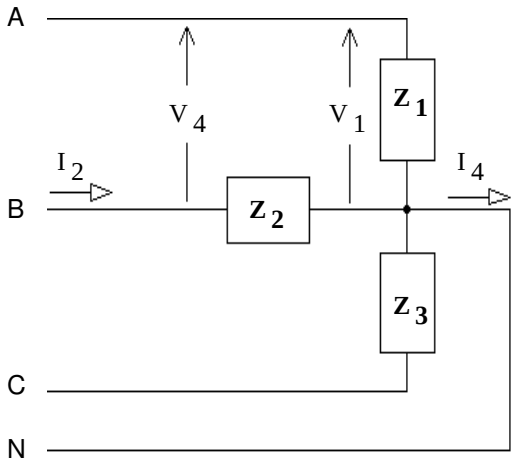
d) Express I_{line} in terms of source real and/or reactive powers and V_S. (Please remember that these variables are all scalar or magnitudes.)

e) Express I_{line} in terms of load real and/or reactive powers and V_L.

f) Express I_{L1} in terms of load real and/or reactive powers and V_L.

g) 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.



a) This is a balanced load, what can be said about the **Z**'s?

b) What is the value V_4? (may be expressed in terms of V_1)

c) What is the value I_4? (may be expressed in terms of I_2)

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

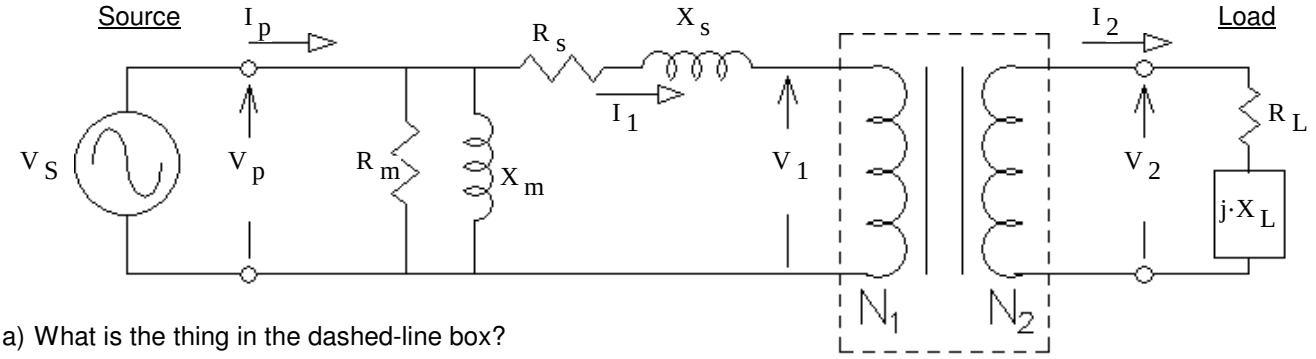
e) Is one of the currents shown also known as the line current? NO YES
If yes, which one?

f) Is this load connected Y or Δ ?

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

$\mathbf{Z_\Delta}$ = OR $\mathbf{Z_Y}$ =

3. A source and load are connected to a model of a non-ideal transformer as shown. 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.

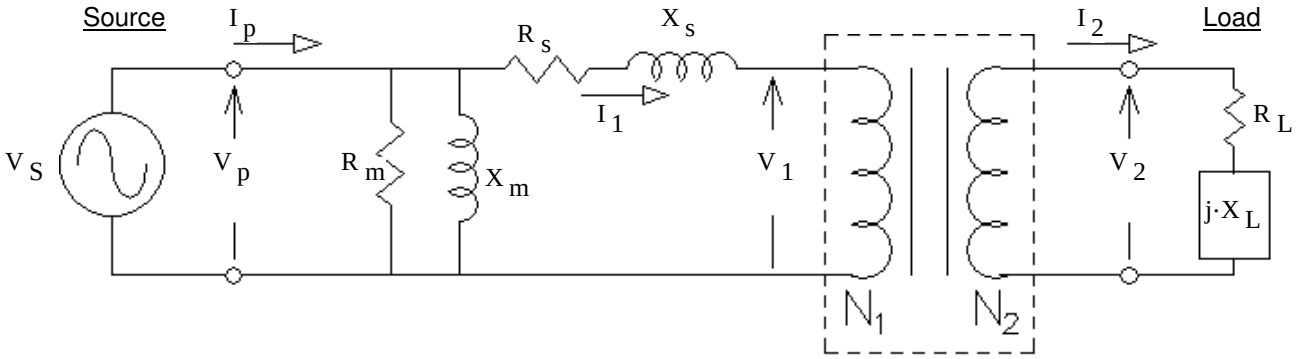


a) What is the thing in the dashed-line box?

b) What is the relationship between V_1 and V_2?

c) What is the relationship between I_1 and I_2?

Same drawing again:



d) Can the dashed-line box and the load be replaced with a simpler equivalent, $R_{eq} + j \cdot X_{eq}$? NO YES

If yes, express: R_{eq} = X_{eq} =

these may be used in expressions below

e) Express I_1 in terms of impedances and V_p. (Please remember that these variables are all scalar or magnitudes.)

f) Express the real power provided by the source in terms of impedances, V_p and I_1 .

g) Express the reactive power provided by the source in terms of impedances, V_p and I_1 .

h) Express I_p in whatever terms you can find above. ("above" means in the figure and/or answers of this problem.)

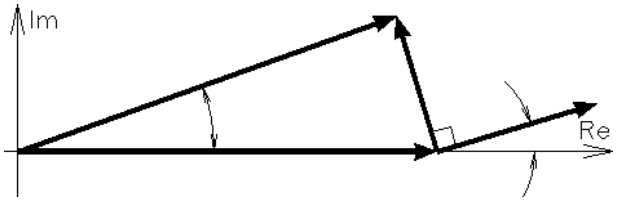
i) Express the efficiency in whatever terms you can find above.

h) Large power transformers are filled with _____ for two main reasons. Give both reasons.

fill in blank

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

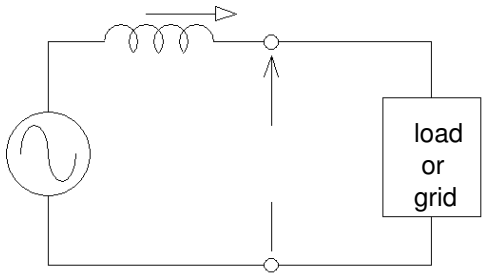
   a) Label all the phasors and angles shown.



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

   c) Judging by the phasor diagram, is the machine making + 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. What is the purpose of the capacitor often used with a single-phase induction motor?

6. How can you reverse the direction of rotation of a capacitor-start single-phase induction motor? Choose from these answers. it starts.

   a) Reverse the leads to the start winding.

   b) Reverse the leads to the main winding.

   c) Reverse the leads to both windings.

   d) Change which winding has the capacitor.

   e) Reverse the leads to the capacitor.

   f) Reverse the positions of the capacitor and the start (second) winding.

7. 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.

   Note: you may also use $k\phi$ below.

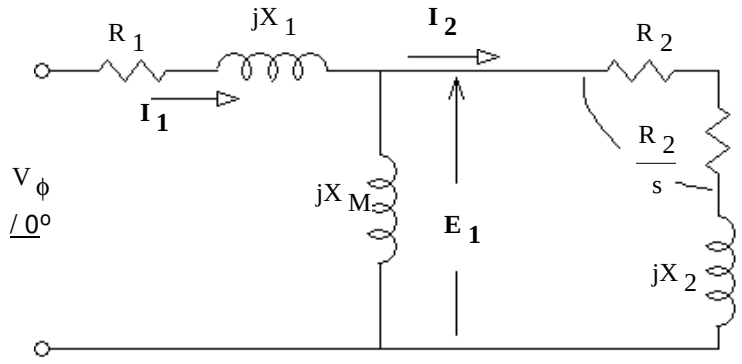
   c) Express the relationship between the induced torque and one or more of the electrical values on your drawing.

   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.

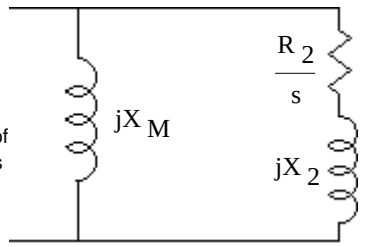
8. The following questions pertain to a 3-phase induction motor.
A model of one phase is shown. Bold variables are complex, all others are scalar.



a) What is the variable "s" called?

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

Z =
Impedance of these 3 parts



c) Write an expression for $\mathbf{E_1}$ in terms of V_ϕ and the impedances given or found above.

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

e) Express the stator-copper-loss of this 3ϕ 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.

9. a) List at least 3 common long-distance high-voltage transmission line voltages given in class.

   b) What insulates the wires from one another in an overhead transmission line?

   c) What does the term "bundling" mean for high-voltage transmission lines?

   d) Name at least 2 important reasons for doing this. (advantages)

   e) Are there disadvantages? Answer no or name one or more.

10. a) The breakers used in substations come in two main types, list them and indicate which type was newer technology.

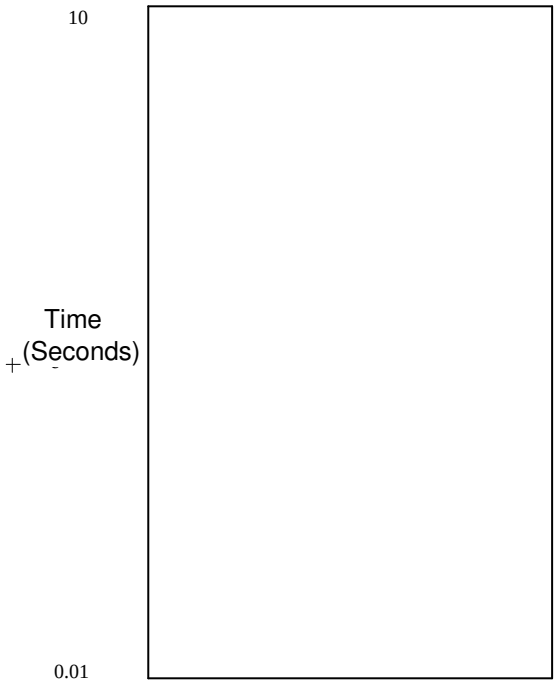
11. b) What devices control these breakers and where are they located?

12. These control devices utilize voltage and current information. What devices in the substation provide that information?

13. 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?

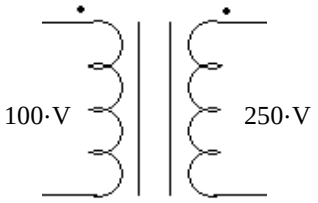
    c) What is the quickest this relay will trip the breaker?



End of Closed-everything part

_____ / 95

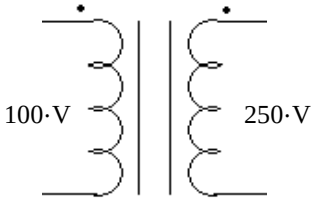
1. (20 pts) You have a 100/250-V, 500-VA transformer.
   a) Can you use this transformer to transform 350 V to 100 V? If yes, show the connections and compute the new VA rating.



   Also show the 350-V source and the load.

   b) Can you use this transformer to transform 80 V to 120 V? If yes, show the connections and compute the maximum **power** that can be transformed at these voltages.

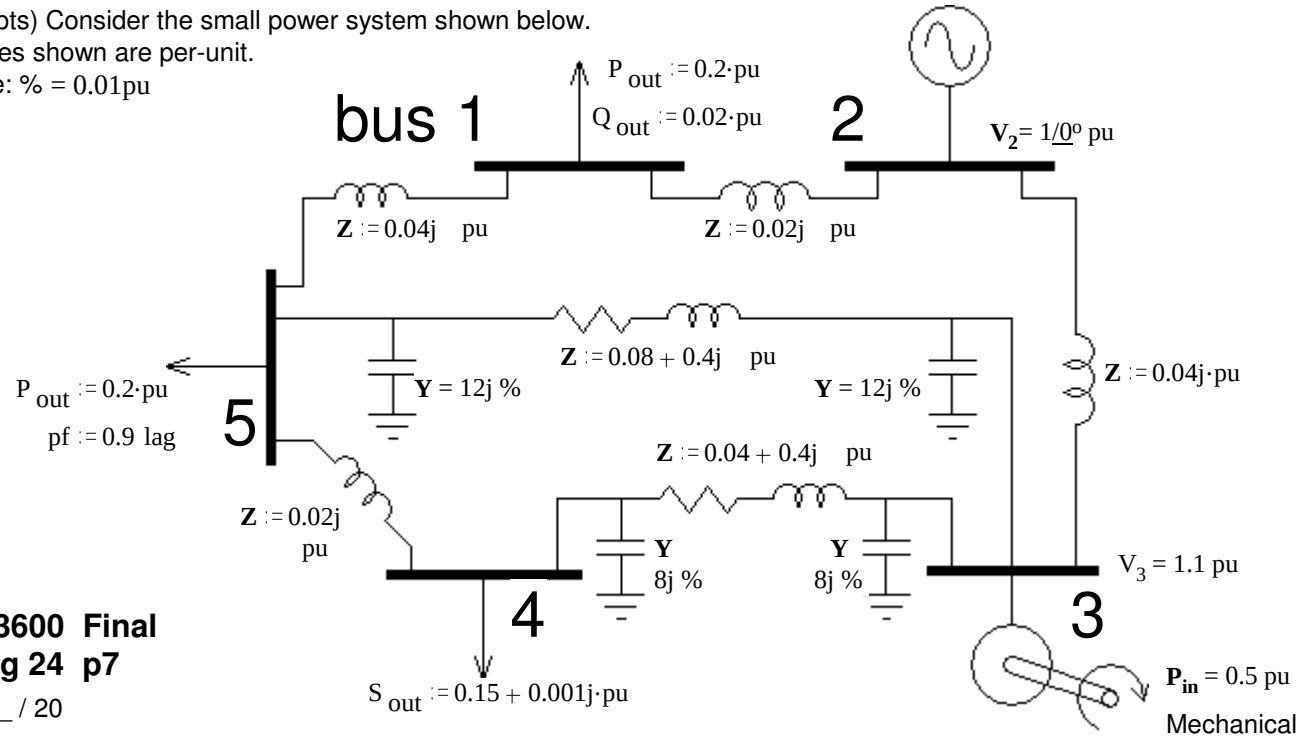
   Hint: $80 \cdot V = \frac{4}{5} \cdot 100 \cdot V$



   Also show the 80-V source and the load.

   c) What condition must be met by the load to transform this maximum power?

2. (25 pts) Consider the small power system shown below. values shown are per-unit.
   Note: % = 0.01pu



1._____ / 20

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

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

b) Show $\mathbf{V_1}$, $\mathbf{V_3}$, $\mathbf{V_4}$ and $\mathbf{V_5}$ on the drawing (as letters, not values).

c) Show $\mathbf{I_1}$, $\mathbf{I_2}$, $\mathbf{I_3}$, $\mathbf{I_4}$ and $\mathbf{I_5}$ on the drawing and draw arrows to indicate the direction of each.

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

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

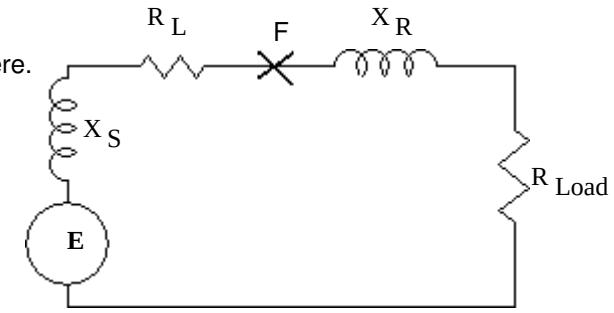
e) A number of the elements of the matrix are zero (0). Fill in all the zero elements, above .

f) Find elements $\mathbf{A}$ and $\mathbf{B}$ in the matrix above. I want numerical answers accurate to ± 0.001 .

3. (40 pts) One phase of a balanced 3-phase system is shown here.

   A fault occurs at point F. Lines B and C open.

   a) Draw the circuit you will have to analyze to find the voltages, $\mathbf{V}_{A1}$, $\mathbf{V}_{A2}$ and $\mathbf{V}_{A0}$.



ALL values below are pu.

$X''_{S1} := 0.1$ $R_{L1} := 0.05$ $X_{R1} := 0.1$ $R_{Load1} := 1.2$

$X''_{S2} := 0.1$ $R_{L2} := 0.05$ $X_{R2} := 0.1$ $R_{Load2} := 1.2$

$X''_{S0} := 0.2$ $R_{L0} := 0.03$ $X_{R0} := 0.1$ $R_{Load0} := 1$

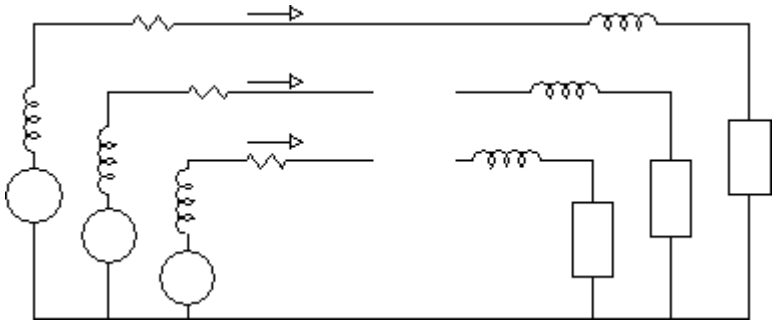
$\mathbf{E''} := 1.2$

More on next page ===>

b) Find the fault voltages, $\mathbf{V_B}$ and $\mathbf{V_C}$. as complex pu values.

c) If the voltage base in the region of the fault was 138kV, find the actual voltages, $\mathbf{V_B}$ and $\mathbf{V_C}$.

d) Show where these voltages ($\mathbf{V_B}$ and $\mathbf{V_C}$) are on the drawing below.



_____ / 40

CB _____ / 95 Total _____ / 180

1. a) $Q_{S1}+Q_{S2} = Q_{Rline}+Q_{L1}+Q_{L2}$ OR $Q_{S1}+Q_{S2} = I_{line}^2\cdot X_{line}+Q_{L1}+Q_{L2}$ b) NO c) NO

d) $I_{line} = \dfrac{\sqrt{(P_{S1}+P_{S2})^2+(Q_{S1}+Q_{S2})^2}}{V_S}$ e) $\dfrac{\sqrt{(P_{L1}+P_{L2})^2+(Q_{L1}+Q_{L2})^2}}{V_L}$ f) $\dfrac{\sqrt{(P_{L1})^2+(Q_{L1})^2}}{V_L}$

g) $\eta = \dfrac{P_{L1}+P_{L2}}{P_{S1}+P_{S2}} = \dfrac{P_{L1}+P_{L2}}{P_{L1}+P_{L2}+P_{Rline}}$ OR

2. a) $\mathbf{Z_1} = \mathbf{Z_2} = \mathbf{Z_3}$ b) $V_4 = \sqrt{3}\cdot V_1$ c) $I_4 = 0$ d) V_4 e) I_2 f) Y g) $\mathbf{Z_\Delta} = 3\cdot\mathbf{Z_Y}$ OR $3\cdot\mathbf{Z_1}$

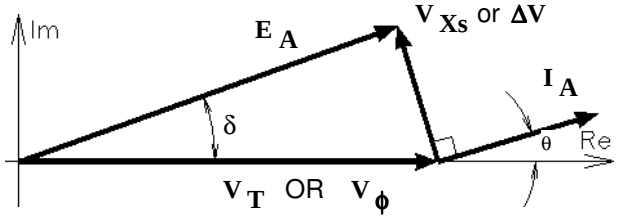
3. a) Ideal transformer b) $\dfrac{V_1}{V_2} = \dfrac{N_1}{N_2}$ c) $\dfrac{I_2}{I_1} = \dfrac{N_1}{N_2}$ d) $R_{eq} = R_L\cdot\left(\dfrac{N_1}{N_2}\right)^2$ $X_{eq} = X_L\cdot\left(\dfrac{N_1}{N_2}\right)^2$ OR $\mathbf{Z_Y} = \dfrac{\mathbf{Z_\Delta}}{3}$

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

g) $\dfrac{V_p^2}{X_m}+I_1^2\cdot(X_s+X_{eq})$ h) $\dfrac{\sqrt{P_S^2+Q_S^2}}{V_p}$ i) $\dfrac{I_1^2\cdot R_{eq}}{P_S}$ h) Oil Oil is a better insulator than air

Oil is used to keep the transformers cool

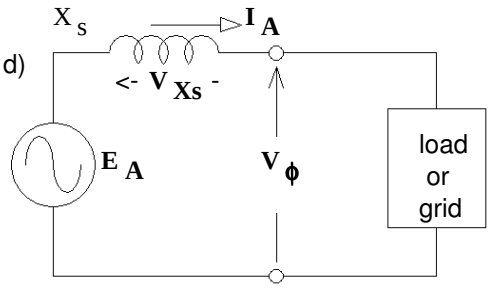
4. a)



b) generator

c) negative

d)

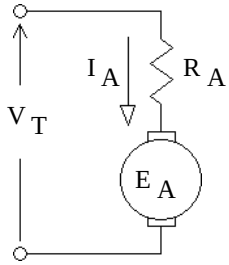


e) $\mathbf{E_A} = \mathbf{V_\phi}+\mathbf{V_{Xs}}$ OR $= \mathbf{V_\phi}+\mathbf{I_A}\cdot j\cdot X_s$

5. Make the current in one of the windings lead the other, so as to get a spinning magnetic field and start the motor.

6. a), b), d)

7. a)



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) $P_{out} = \tau_{shaft}\cdot\omega_m$

8. a) The slip b) $\mathbf{Z} = \dfrac{1}{\frac{1}{j\cdot X_m}+\frac{1}{\left(\frac{R_2}{s}+j\cdot X_2\right)}}$ c) $\mathbf{E_1} = V_\phi\cdot\dfrac{\mathbf{Z}}{R_1+j\cdot X_1+\mathbf{Z}}$

d) $|\mathbf{I_2}| = \dfrac{|\mathbf{E_1}|}{\sqrt{\left(\frac{R_2}{s}\right)^2+X_2^2}} = \left|\dfrac{\mathbf{E_1}}{\frac{R_2}{s}+j\cdot X_2}\right|$

e) $P_{SCL} = 3\cdot\left[\left(|\mathbf{I_1}|\right)^2\cdot R_1\right]$ f) $P_{RCL} = 3\cdot\left[\left(|\mathbf{I_2}|\right)^2\cdot R_2\right]$

g) $P_{AG} = 3\cdot\left[\left(|\mathbf{I_2}|\right)^2\cdot\dfrac{R_2}{s}\right]$ h) $P_{conv} = (1-s)\cdot P_{AG} = P_{AG}-P_{RCL}$

9. a) 3 of these: $115\cdot kV$ $230\cdot kV$ $345\cdot kV$ $500\cdot kV$ $765\cdot kV$ b) Air (and distance) c) Using more than one conductor per phase.

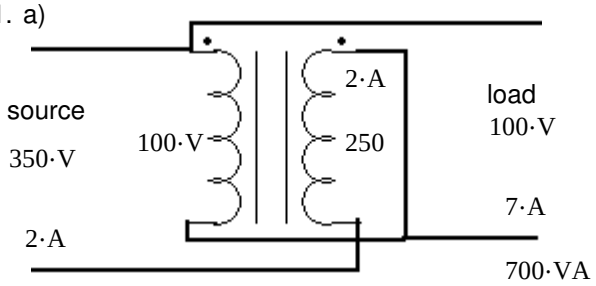
d) 2 of these: Reduce corona discharge Decrease line inductance Increase line capacitance e) Costs more

10. Oil filled (old) Gas (SF_6) filled (newer) 11. Relays in the control buildings

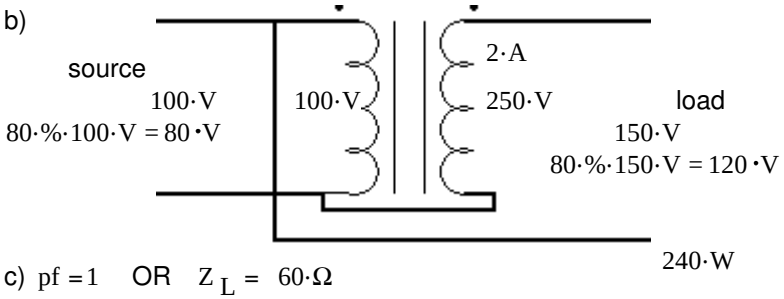
12. Current transformers (CTs) Voltage or Potential Transformers (VTs or PTs)

13. a) $3\cdot sec$ b) $0.09\cdot sec$ c) $0.03\cdot sec$

1. a)



b)



c) pf = 1 OR $Z_L = 60\cdot\Omega$

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

b) voltages at each bus

c) currents at each bus, flowing in from outside the system

d) Admittance, Bus, or Bus admittance matrix

e)

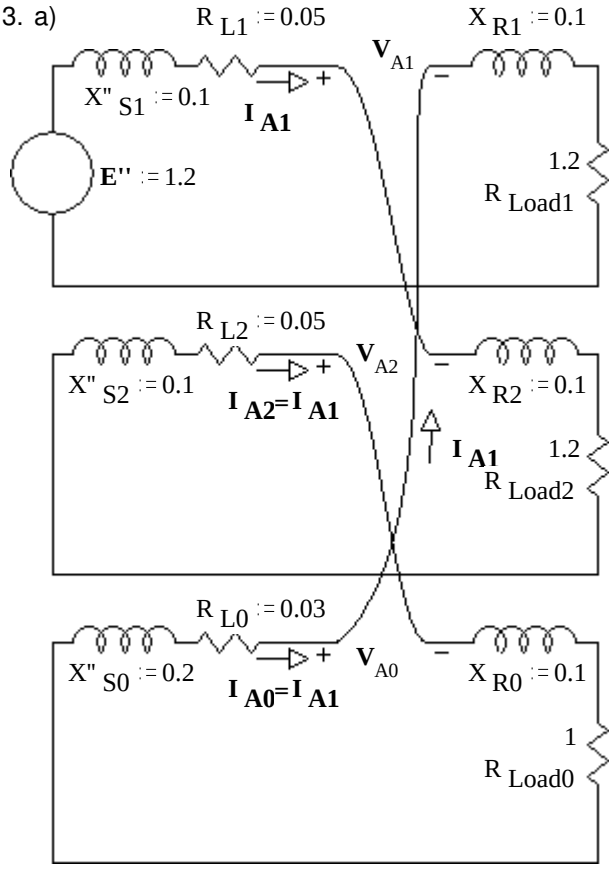
$$\begin{bmatrix} \_\_ & \_\_ & 0 & 0 & \_\_ \\ \_\_ & \_\_ & \_\_ & 0 & 0 \\ 0 & \_\_ & \_\_ & \_\_ & \_\_ \\ 0 & 0 & \_\_ & \_\_ & \mathbf{A} \\ \_\_ & 0 & \_\_ & \_\_ & \mathbf{B} \end{bmatrix}$$

f) $50\cdot j$

$0.481 - 77.284\cdot j =$

$77.285\text{pu} \angle -89.644^\circ$

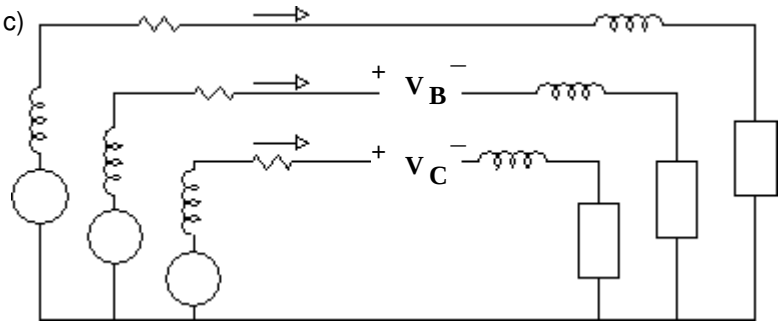
3. a)



b) $1.211\text{pu} \angle -116.2^\circ$ $1.127\text{pu} \angle 118.3^\circ$

c) $96.454\text{kV} \angle -116.2^\circ$ $89.799\text{kV} \angle 118.3^\circ$

c)



Which simplifies to: