ECE3600 Final given: Fall 23

Write Legibly! Closed book, Closed notes, Calculator OK. 12/11/23

1. Large power transformers are filled with ________________ for two main reasons. Give both reasons.
fill in blank

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

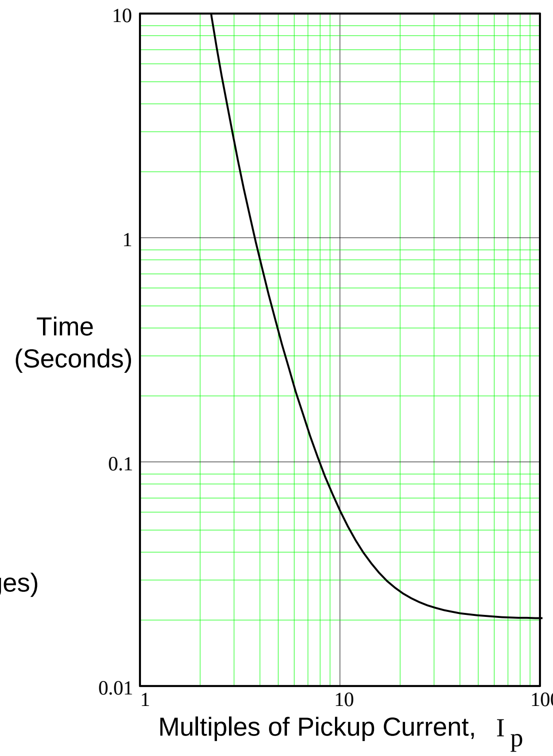
3. What devices control these breakers and where are they located?

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

5. 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?

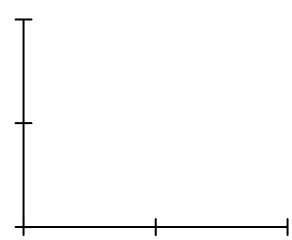


6. a) What does the term "bundling" mean for high-voltage transmission lines?

   b) Name the 2 of the most important reasons for doing this. (advantages)

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

7. a) In the space at right, sketch the torque-speed curve of a series-wound DC motor (field in series with rotor).



   b) If this type of motor is used with an AC source, what is it called?

   c) Name at least 2 common uses of this type of motor.

8. How can you reverse the direction of rotation of a 3-phase motor? Induction or synchronous. Choose from these answers. Circle all answers that would work

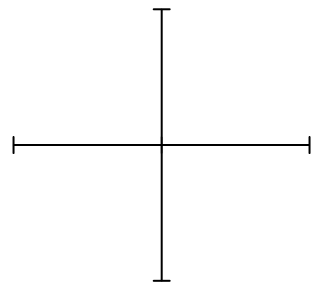
   a) Move phase A to B, B to C, and C to A at the power panel.

   b) Swap any two phases at the power panel.

   c) Change the wiring within the motor to reverse the current in one of the windings.

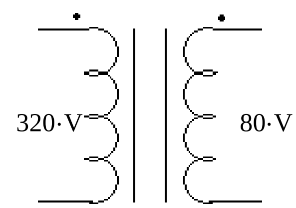
9. a) Name at least 3 issues caused by the B-H hysteresis curve.

   b) Draw a B-H curve & label both axes.



10. You have a 320/80-V, 960-VA transformer.

   a) Can you use this transformer to transform 320 V to 240 V? If yes, show the connections and compute the new VA rating.



   Also show the 320-V source and the load.

   b) Can you use this transformer to transform 160 V to 120 V? If yes, what is the maximum real power that could be trasformed?

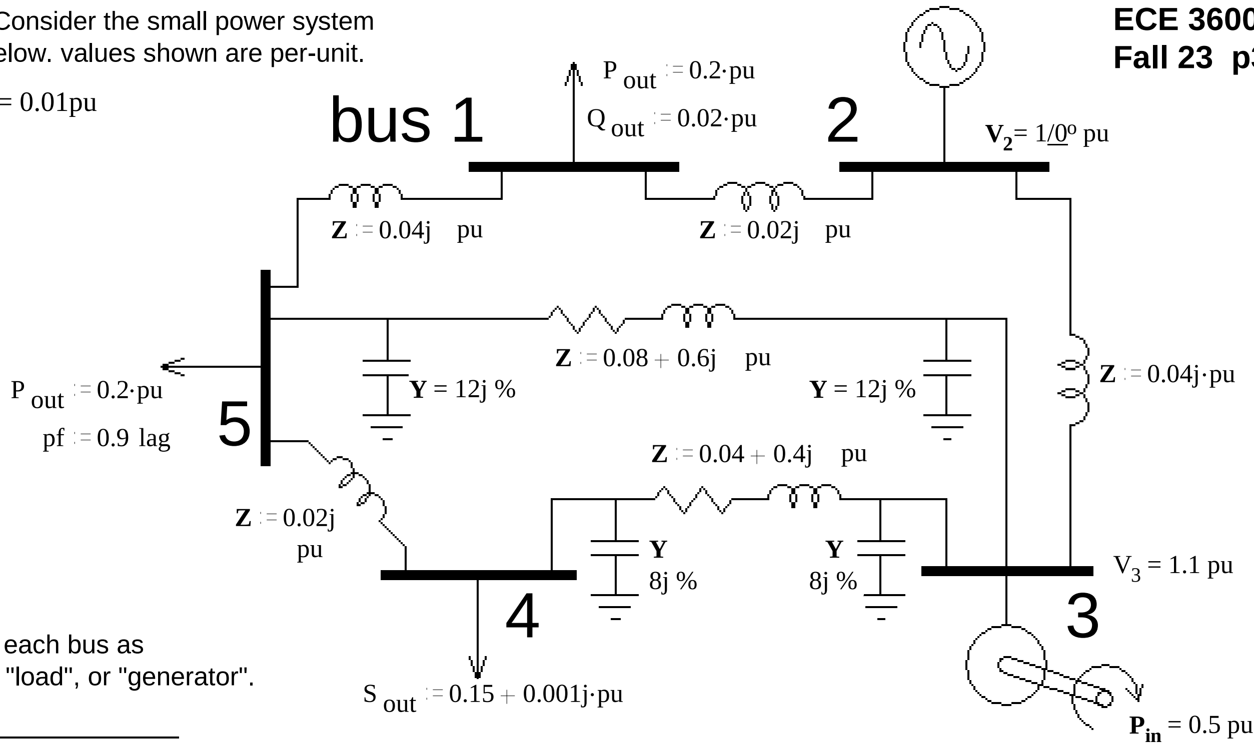
   c) Is there a requirement for the load to actually transform this much real power? if yes, say what.

11. When accounting for the non-ideal characteristics of a power transformer, which of the following is the most important (least often neglected)?

   magnetization reactance   leakage reactance   core losses   winding losses

1. (24 pts) Consider the small power system shown below. values shown are per-unit.

   Note: % = 0.01pu



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

   bus 1. ______________

   2. ______________

   3. ______________ 4. ______________ 5. ______________

b) Show V_1, V_3, 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.

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.

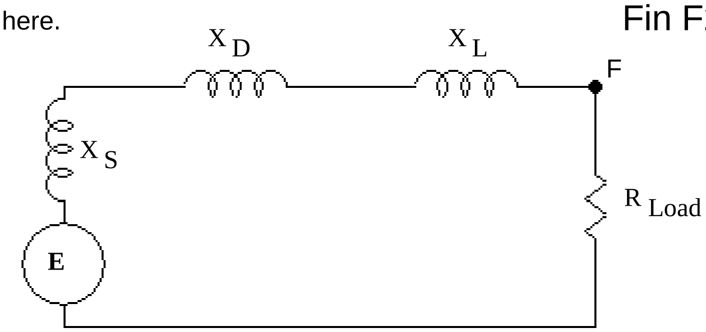
f) Find elements **A** and **B** in the matrix above. I want numerical answers accurate to ± 0.001 .

2. (22 pts) One phase of a balanced 3-phase system is shown here.

   A fault occurs at point F. It is a short between lines b and c with an impedance of $\mathbf{Z_f}$.

   a) Draw the circuit you would have to analyze to find the fault current. Identify the parts and Include the component voltages and currents at the fault.

   b) Set up a mathematical expression (or expressions) to find the fault current. (don't forget j & that the fault current is NOT $\mathbf{I}_{A1}$)



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3. (36 pts) A 230 kV (nominal) transmission line has the following length and line parameters. $S := \text{siemens}$ **Fin F23**

$len := 200 \cdot km$ $r = ?$ $x = ?$ (will be found in problem) $g := 0 \cdot \frac{S}{km}$ $y := 4 \cdot 10^{-6} \cdot \frac{S}{km}$

a) Choose the most appropriate model for this transmission line and draw it, including the impedance and/or admittance value(s) you can find at this time. Add a 3ϕ load at the receiving end of the transmission line.

The line voltage at both the sending and the recieving end are both 230kV. The power angle is 12º. $\delta := 12 \cdot deg$

The load at the recieving end is $S_R := 93 \cdot MVA$ it's power factor is 0.95.

b) Judging by the voltages, the load power factor is most likely: leading lagging (circle one)

c) Find the line current to the **load**, $\mathbf{I_R}$ (not $\mathbf{I_{Line}}$) as a complex number.
Clearly state what you are using as the 0º reference.

d) Find the impedance of one phase of the load, assuming Y-connected.

e) Find the line current in your model, $\mathbf{I}_{\mathbf{Line}}$ (not $\mathbf{I}_{\mathbf{S}}$) in a complex-number form. $\mathbf{I}_{\mathbf{Line}}$ = ?

f) Find the series impedance of the line. $\mathbf{Z}_{\mathbf{series}}$ =?

If your answer to for $\mathbf{Z}_{\mathbf{series}}$ comes out unreasonable, go back and rethink your answer to part b).
Rework your other answers as necessary.

g) Find the missing line parameters. r = ? x = ?

h) How much real power does the source supply?

i) What is the effiency of this line?

4. (35 pts) A separately excited dc motor is rated at 2-hp, 1200rpm, armature: $150\ V$ $14.5A$, field: $150\ V$ $0.8A$.

$1 \cdot hp = 745.7 \cdot W$

a) The field is connected to the rated voltage and then you spin this motor with another device at 900rpm. The dc motor is connected to a voltmeter and nothing else. You measure the terminal voltage at $92\ V$. Find R_A from this information and the ratings.

If you can't find R_A, mark an X here ______ and use 2Ω for the rest of the problem.

Unless stated otherwise, assume rated voltages below.

b) Find the rotational losses at when operated at full load. $P_{rot} = ?$

c) Find the overall efficiency (includes power needed for the field) when operated at full load.

d) Find the no-load armature current. Show the algebra needed to find I_A from the basic equations.
The rotational losses are proportional to the motor speed.
Hint 1: This also means that the rotational losses are proportional to E_A, like this: $P_{rot2} = P_{rot1} \cdot \frac{E_{A2}}{E_{A1}}$
Hint 2: This turns out to be amazingly easy to calculate, no quadratic required.

e) Find the no-load shaft speed.

f) The mechanical load on the shaft is increased and the motor slows down to: $n_{new} := 1300 \cdot rpm$

Find the load power at this speed.

g) The field voltage is reduced to 120V and the armature is left at the rated voltage.
The load is then adjusted so that the speed is again 1300rpm.

Find the armature current at this field voltage.

h) Would it be OK to operate this way for a long time?

TURN OVER, Last problem on back ====>

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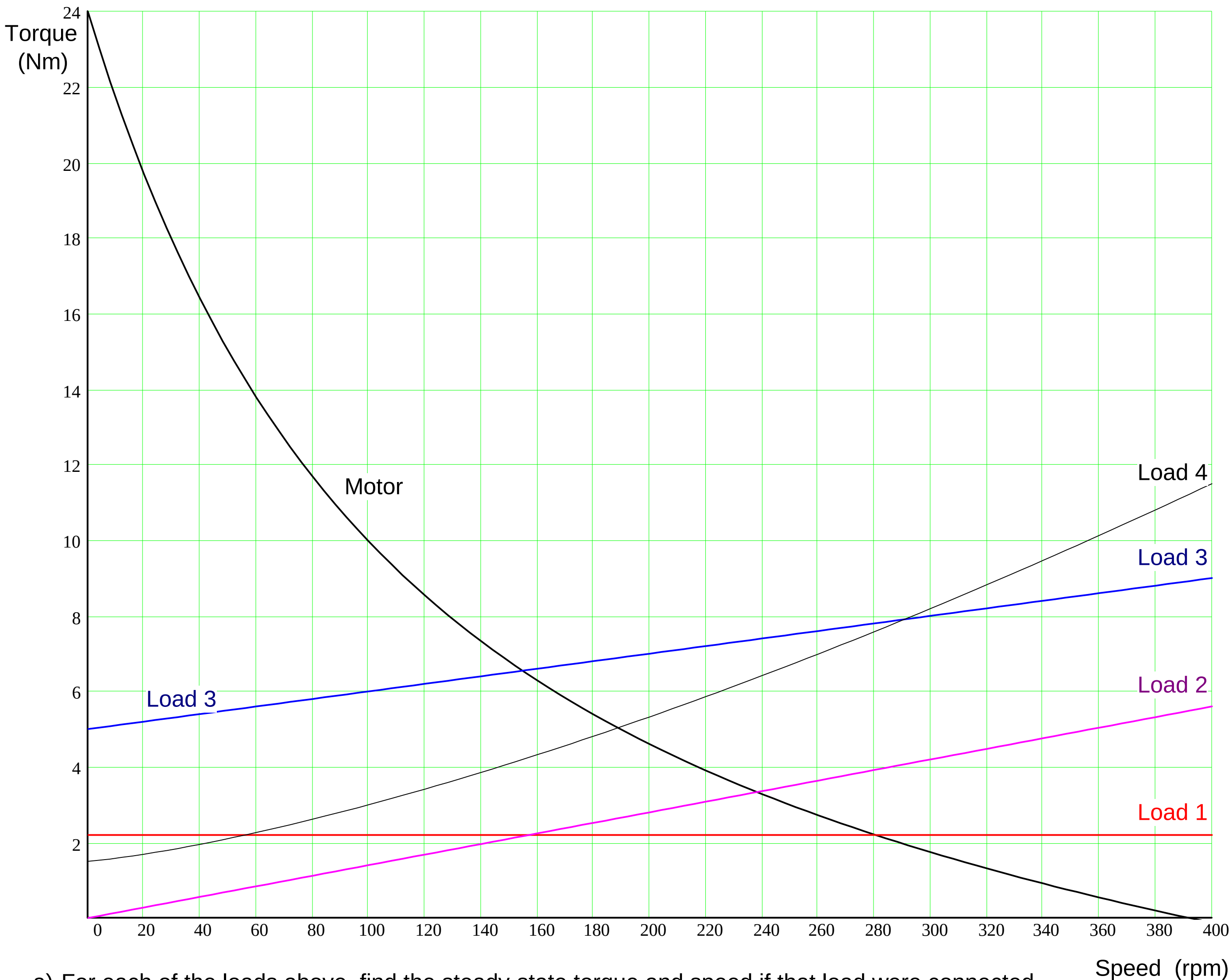
5. (20 pts) A motor's torque-speed curve is shown below (dark line). Several load curves are also shown



a) For each of the loads above, find the steady-state torque and speed if that load were connected to the motor.

Load 1 ____________ ____________

Load 2 ____________ ____________

Load 3 ____________ ____________

Load 4 ____________ ____________

b) For each of the loads, say what kind of load it is and/or give an example.

Load 1

Load 2

Load 3

Load 4

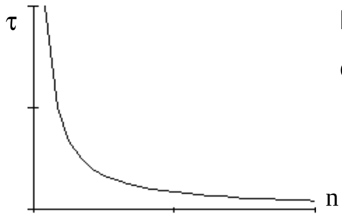
c) What type of motor do you think this is?

_____ / 20

CB _____ / 42 Total _______ / 180

1. Oil Oil is a better insulator than air Oil is used to keep the transformers cool
2. Oil filled (old) Gas (SF_6) filled (newer) 3. Relays in the control buildings
4. Current transformers (CTs) Voltage or Potential Transformers (VTs or PTs) 5. a) $3\cdot sec$ b) $0.06\cdot sec$ c) $0.02\cdot sec$
6. a) Using more than one conductor per phase.
   b) Reduce corona discharge Decrease line inductance Increase line capacitance 2 of these c) Costs more

7. a)



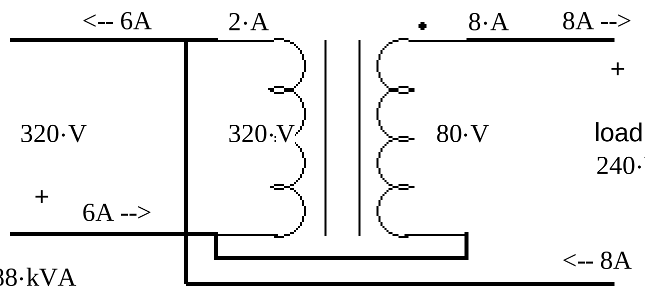
b) Universal motor

c) Hand drill Vacuum cleaner
Blender Food processor
Weed eater Electric yard devices
etc.

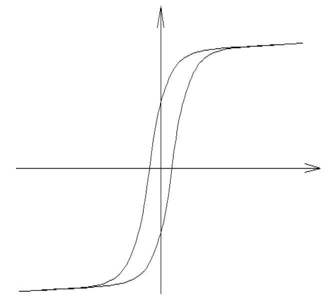
8. b)

9. a) Core losses
Nonlinearities, esp. in the currents
Sets voltage limits
Requires larger, heavier cores
3rd harmonic currents
Requires more windings so that the core flux can be less

10. a)

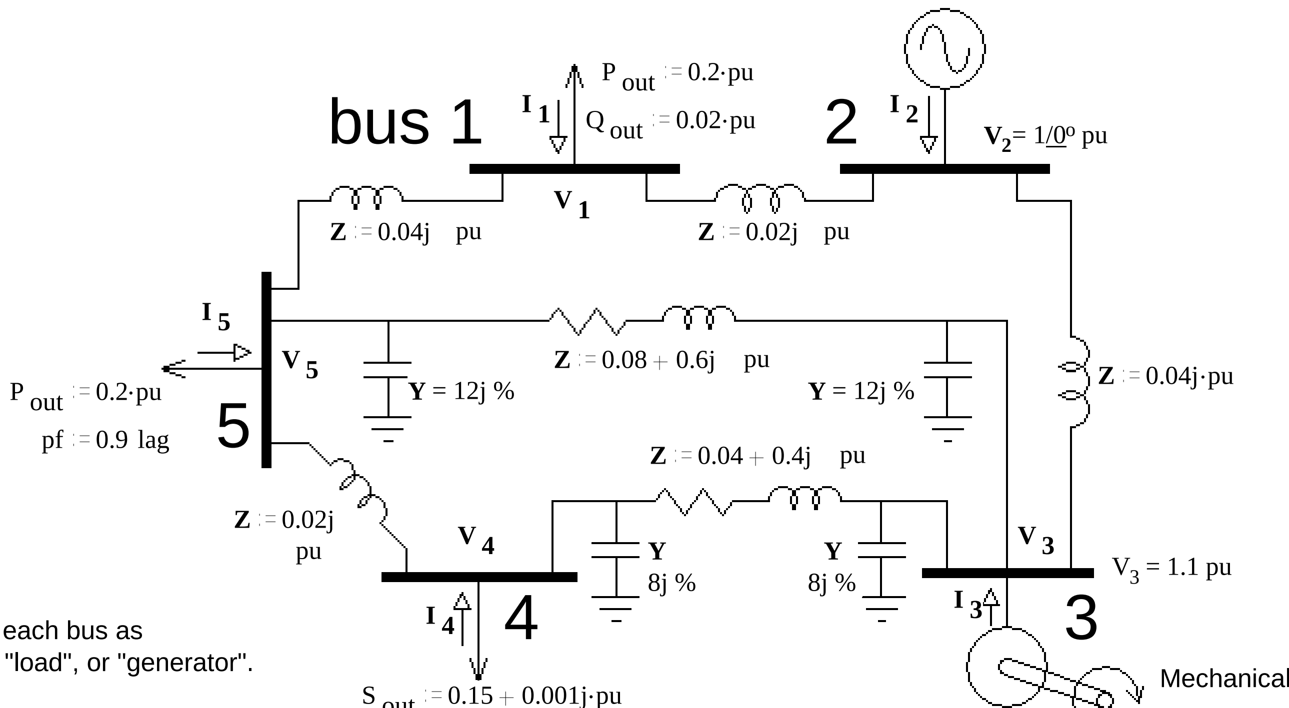


b)



b) YES, half voltages above $1.44\cdot kW$
c) YES, pf = 1 11. leakage reactance

1. a) bus 1. load 2. slack 3. generator 4. load 5. load



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

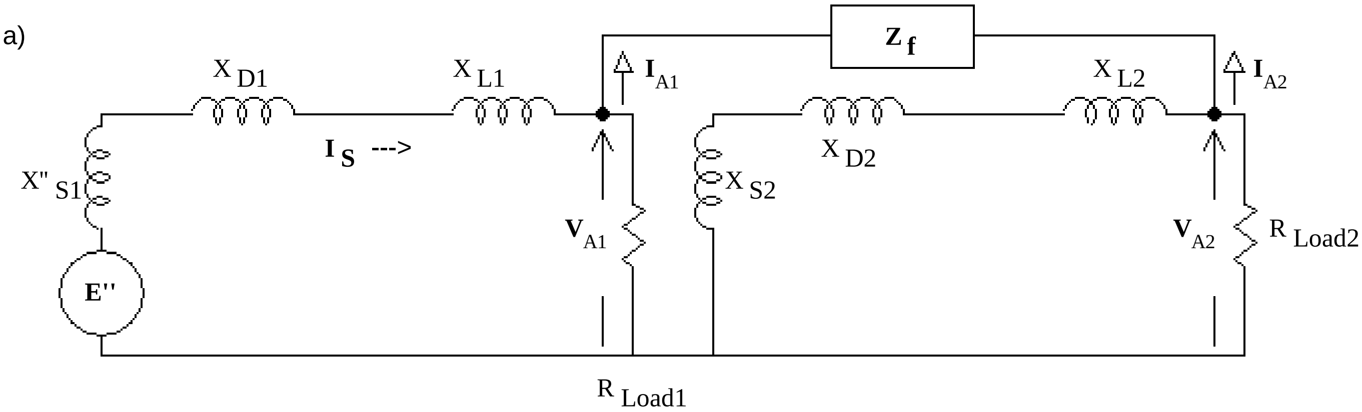
d) Admittance, Bus, or Bus admittance matrix

e)
$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{bmatrix} = \begin{bmatrix} \_\_ & \_\_ & 0 & 0 & \_\_ \\ \_\_ & \_\_ & \_\_ & 0 & 0 \\ 0 & \_\_ & \_\_ & \mathbf{A} & \_\_ \\ 0 & 0 & \_\_ & \mathbf{B} & \_\_ \\ \_\_ & 0 & \_\_ & \_\_ & \_\_ \end{bmatrix} \cdot \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \end{bmatrix}$$

f) $\mathbf{A} = (-0.248 + 2.475\cdot j)\cdot pu$

$\mathbf{B} = (0.248 - 52.395\cdot j)\cdot pu$

2. a)

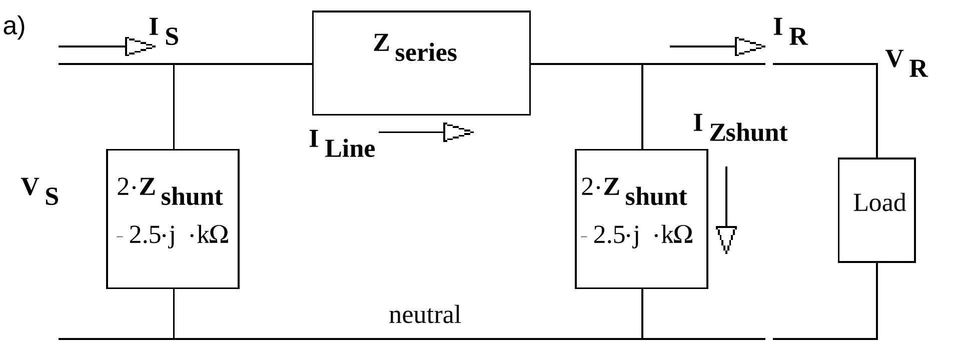


b) $\mathbf{Z_X} = \mathbf{Z_f} + \dfrac{1}{\dfrac{1}{(X_{S2} + X_{D2} + X_{L2})\cdot j} + \dfrac{1}{R_{Load2}}}$

$\mathbf{I_S} = \dfrac{\mathbf{E''}}{(X''_{S1} + X_{D1} + X_{L1})\cdot j + \left(\dfrac{1}{\dfrac{1}{R_{Load1}} + \dfrac{1}{\mathbf{Z_X}}}\right)}$

$\mathbf{V_{A1}} = \mathbf{I_S}\cdot\dfrac{1}{\left(\dfrac{1}{R_{Load1}} + \dfrac{1}{\mathbf{Z_X}}\right)}$ $\mathbf{I_{A1}} = \dfrac{\mathbf{V_{A1}}}{\mathbf{Z_X}}$ $\mathbf{I_{fault}} = \mathbf{I_B} = \sqrt{3}\,\angle -90°$

3. a)



b) leading

c) $221.8 + 72.9\cdot j$ A

d) $540.4 - 177.6\cdot j$ Ω

e) $221.8 + 126.0\cdot j$ A

f) $43.58 + 99.73\cdot j$ Ω

g) $0.218\cdot\Omega$ $0.499\cdot\Omega$

h) $96.86\cdot MW$ i) $91.22\cdot\%$

4. a) $1.885\cdot\Omega$ b) 287.3 c) $64.98\cdot\%$

d) $2.342\cdot A$ e) $1424\cdot rpm$ f) $895\cdot W$ g) $23.18\cdot A$ h) NO

5. a)

Load 1	$280\cdot rpm$	$2.2\cdot N\cdot m$	b) Constant-torque, power proportional to speed. Ex: lift object without friction.
Load 2	$238\cdot rpm$	$3.3\cdot N\cdot m$	Torque proportional to speed, power proportional to speed squared. Ex: simple friction, no lift.
Load 3	$155\cdot rpm$	$6.5\cdot N\cdot m$	Mix of two types above. Ex: elevator, crane, etc..
Load 4	$189\cdot rpm$	$5\cdot N\cdot m$	Like load 3, but friction isn't linear. Ex: pump or fan (fan initial torque would be smaller).

c) Series-excited DC