ECE3600 Final given: Fall 21 p1

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

(15 pts) Questions If I can't read what you've written or you answer is ambiguous, I'll assume you don't know.

1. Why does a DC motor have brushes and a commutator?

2. How can you reverse the direction of rotation of a capacitor-start motor? That is, reverse the direction it starts. Choose **ALL** the possible ways from these answers:

   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.

3. Most electric motors that we studied draw more current if the mechanical load is increased. Are there any that do not (in normal operating range)? Either answer NO or name the exception(s) and indicate how they do respond to increased mechanical load.

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

   b) It is typically used for transmission lines with line voltages $\geq$ ______________ fill in blank

   c) Name the 3 most important reasons for doing this. (advantages)

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

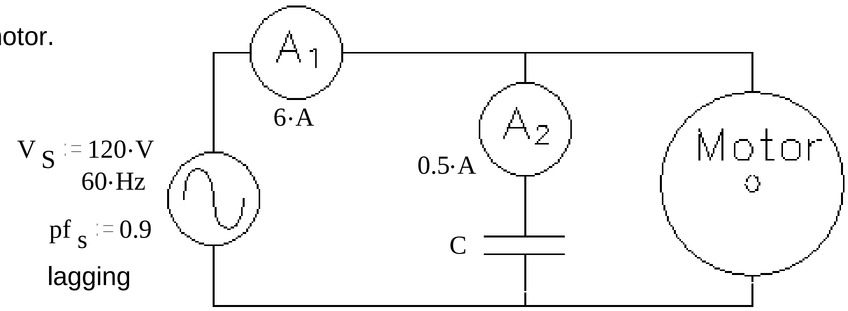
Return this part of the exam and get part 2

_____ / 15

1. (25 pts) A capacitor (C) is used to partially correct the power factor of a motor to 0.9. That is, the power factor as seen by the source is 0.9. Two ammeters (A_1 and A_2) read the currents shown.

Find the following:

a) The original power factor of the motor.
As part of your solution, find the P and Q of the motor.



If you can't find this power factor, mark an x here _____ and assume $pf_m = 0.85$ for the rest of the problem.
You may salvage some points from a) if you find the motor Q from this pf_m , otherwise skip to b)

b) How much current flows through the motor (magnitude).

c) Add an additional component to the drawing above in order to completely correct the power factor.
Find the value of the component.

2. (30 pts) A 3-phase, Δ-connected, induction motor has the following equivalent circuit components:

$R_1 := 0.2 \cdot \Omega$ $\quad R_2 := 0.5 \cdot \Omega$ $\quad R_C := \infty$ $\quad$ currently running at $n := 1710 \cdot \text{rpm}$

$X_1 := 0.4 \cdot \Omega$ $\quad X_2 := 0.6 \cdot \Omega$ $\quad X_M := 15 \cdot \Omega$

DON'T FORGET: Your powers are for the whole motor and your model is only for ONE phase.

a) Draw the circuit model of one phase, and label the known parts and values.

b) Find the slip. Make a reasonable assumption as necessary.

c) The output shaft torque is $\tau_{load} := 60 \cdot N \cdot m$ Find the output power

d) The mechanical power losses (all lumped together) is $P_{mech\_loss} := 400 \cdot W$ Find P_{conv}

e) Find $|\mathbf{I}_2|$

f) Find the line current. Note: Don't try any shortcuts here. You need to do your math with full complex numbers. I advise you to assume the phase angle of $\mathbf{I}_2$ is 0º.

$|\mathbf{I}_L| = ?$

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g) Find P_{RCL}

h) The stator copper losses P_{SCL}

i) The overall machine efficiency η

3. (22 pts) A 1/3-hp, 120-V, 60-Hz, single-phase, capacitor-run, induction motor has two windings set 90º apart in the motor housing. The windings are NOT the same. At **normal run speed**, winding 1 draws 3.7 A at 40° lag. Winding 2 in series with an 70-µF capacitor draws 3.6 A at 50° lead.

$V_T := 120 \cdot V$ $\quad$ $\mathbf{I_{1run}} := 3.7 \cdot A \cdot e^{-j \cdot 40 \cdot deg}$ $\quad$ $\mathbf{I_{2run}} := 3.6 \cdot A \cdot e^{j \cdot 50 \cdot deg}$ which includes a series $C := 70 \cdot \mu F$

a) Find the run-speed impedances of winding 1 and winding 2 without the capacitor. Find both in rectangular form.

3. b) At **startup**, the winding impedances are found to be:

$\mathbf{Z_{1strt}} := (8 + 10 \cdot j) \cdot \Omega$ $\quad$ $\mathbf{Z_{2strt}} := (8 + 14 \cdot j) \cdot \Omega$ without capacitor

Find the ideal capacitor to place in series with winding 2 at **startup**.
Note: the ideal capacitor would create the ideal phase difference between the winding currents.

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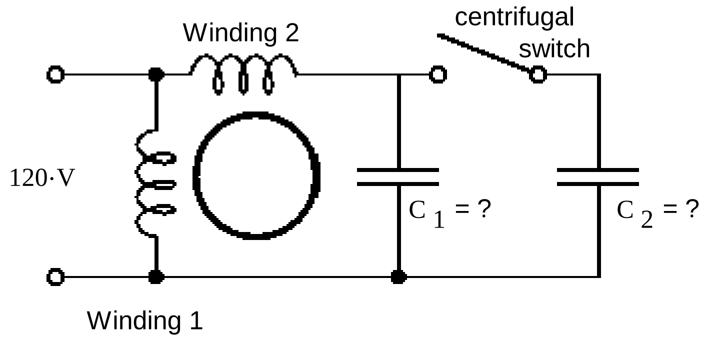
c) The motor has a centrifugal switch which switches at half speed. See drawing, below.

Circle one:
i) The centrifugal switch should be closed at start and open (as shown) at run speed.
ii) The centrifugal switch should be open (as shown) at start and closed at run speed.

Find the values of the two capacitors below so as to meet the conditions of parts a) and b). Write them down below.



4. (36 pts) A 1.5-hp, separately excited dc motor runs at 58% overall efficiency (includes power needed for the field) when operated at full load. Both the armature and field are hooked to a single 180 V source. The rotational losses are proportional to the motor speed squared. Other important information is given below.

$\eta := 58 \cdot \%$ $\quad V_T := 180 \cdot V$ $\quad n_{fL} := 900 \cdot rpm$ $\quad R_A := 3 \cdot \Omega$ $\quad R_F := 300 \cdot \Omega$ $\quad 1 \cdot hp = 745.7 \cdot W$

a) At full load, find the power converted from electrical to mechanical, $P_{conv} = ?$
This is a multi-step calculation.

b) At full load, find the rotational losses, $P_{rot} = ?$

c) The **mechanical load** on the shaft is **reduced** and the motor speeds up to: $n_{new} := 950 \cdot rpm$

The full-load speed is given above as $n_{fL} = 900 \cdot rpm$ Find the load power, P_{out} , at this speed.

The torque required to overcome the rotational losses is proportional to the motor speed. Therefore,

the rotational loss power is proportional to the motor speed squared. $P_{rot2} = P_{rot1} \cdot \frac{n_2^{\;2}}{n_1^{\;2}}$ be sure to clearly account for this.
The relationship between P_{out} and the speed is **unknown**.

This is a multi-step calculation. $P_{out} = ?$

The **load** is now **removed completely**.

d) Find the no-load shaft speed. Remember, the rotational losses are proportional to the motor speed squared.

Hint 1: This also means that the rotational losses are proportional to $E_A{}^2$, like this: $P_{rot2} = P_{rot1} \cdot \frac{E_{A2}{}^2}{E_{A1}{}^2}$

Hint 2: This is NOT trivial to calculate, you will need to go back to basic DC motor equations and make some substitutions. More hints are available for points, come ask.

Show the algebra needed to find E_A from the basic equations. (Yeah, algebra is a prerequisite for Engineering.)

The full-load speed is given above as $n_{fL} = 900 \cdot rpm$ Find the no-load shaft speed.

If you can't find E_A , mark an X here ______ use $E_A := 175 \cdot V$ to find the speed, above and the next answer.

e) Find the no-load armature current. I_A = ?

5. (32 pts) A 345 kV transmission line has the following length and line parameters. $S := \text{siemens}$

$len := 180 \cdot km$ $\quad r := 0.08 \cdot \frac{\Omega}{km}$ $\quad x := 0.75 \cdot \frac{\Omega}{km}$ $\quad g := 0 \cdot \frac{S}{km}$ $\quad y := 5 \cdot 10^{-6} \cdot \frac{S}{km}$

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

The line voltage at the **source** is 345kV.

The transmission line current ($\mathbf{I_{Line}}$) is 240A and it **leads** the line-to-neutral voltage by 6°.

b) Find the line current from the **source** ($\mathbf{I_S}$) in your model in a complex-number form. $\mathbf{I_S}$ = ?

c) Find the load phase voltage, $\mathbf{V_R}$, magnitude and phase. $\mathbf{V_R}$ = ?

More on next page ===>

d) What is the line voltage at the load (magnitude)?

e) What is the "power angle" (δ)?

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

g) Find the power consumed by the entire load.

h) Find the power factor of the load.

Answers

1. The commutator is a series of bars or segments so connected to armature coils of a generator or motor that rotation of the armature will in conjunction with fixed brushes result in unidirectional current output in the case of a generator and in the reversal of the current into the coils in the case of a motor.

2. a) b) d)   3. NO, all electric motors draw more current if the mechanical load is increased

4. a) Using more than one conductor per phase.   b) $345 \cdot kV$

   c) Reduce corona discharge   Decrease line inductance   Increase line capacitance   d) Costs more

With notes

1. a) 0.866 b) $6.234 \cdot A$ c) $57.8 \cdot \mu F$
2. b) $5 \cdot \%$ c) $10.74 \cdot kW$ d) $11.14 \cdot kW$ e) $19.77 \cdot A$ f) $42.3 \cdot A$ g) $586.5 \cdot W$ h) $358 \cdot W$ i) $88.9 \cdot \%$
3. a) $24.84 + 20.85 \cdot j\ \Omega$ $21.43 + 12.36 \cdot j\ \Omega$ b) $130 \cdot \mu F$ c) $70 \cdot \mu F$ $60 \cdot \mu F$
4. a) $1514 \cdot W$ b) $395 \cdot W$ c) $720 \cdot W$ d) $1028 \cdot rpm$ e) $3.016 \cdot A$
5. b) $264.8 \cdot A$ $25.67 \cdot deg$ c) $201 \cdot 8 \cdot kV$ $-9.293 \cdot deg$ d) $349.5 \cdot kV$

   e) $9.293 \cdot deg$ f) $865.5 \cdot \Omega$ $6.775 \cdot deg$ g) $140 \cdot MW$ h) 0.993