First name:

Last name: **Student ID:**

ELEC0431 — Electromagnetic Energy Conversion

Written Exam

June 2024

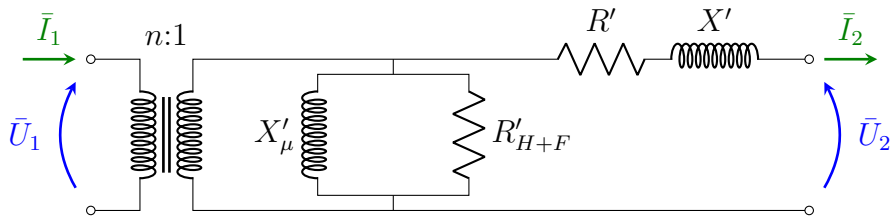
- You have three hours to complete the exam.
- Do not forget to mention your name and student ID on the first page.
- Read carefully each question and answer on the questionnaire, within the provided spaces.
- There are two white pages at the end of your questionnaire. You can use them if you run out of space for a question. If you use them, clearly notify it.
- Do not unstaple the questionnaire.
- Draft white pages are also provided. You can use them to prepare your answers, but they will not be corrected.
- Red color is forbidden.
- Calculators are allowed, but smartphones and connected watches are strictly forbidden.
- You are free to **answer in English or in French**.

Bon travail !

Transformers

Question 1

The following schematic presents the equivalent model of a single-phase transformer, with impedances gathered and moved to the secondary winding.



During a short-circuit test, an active power $P = 300$ W is measured for a primary RMS voltage $U_1 = 100$ V and a primary RMS current $I_1 = 5$ A. Deduce the appropriate impedance values, considering a transformer ratio $n = 10$ and assuming $R', X' \ll X'_\mu, R'_{H+F}$.

Answer: $R' = 120\ m\Omega$ and $X' = 160\ m\Omega$

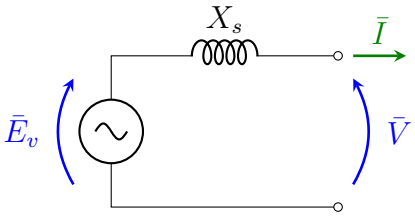
Question 2

For each of the below affirmations, select if it is true (T) or false (F) (right +1, wrong -0.5, min. 0).

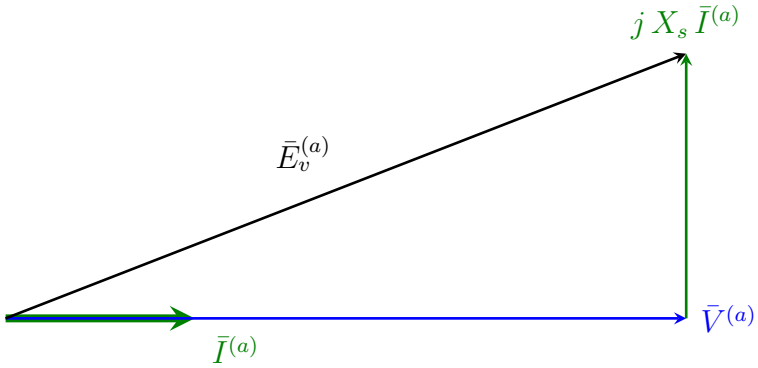
T	F	
☒	☐	Consider an ideal three-phase transformer whose primary is connected to an ideal three-phase power source, and whose secondary is open-circuited. The secondary line voltage in Δ-Y configuration is three times the secondary line voltage in Y-Δ configuration.
☒	☐	The magnetizing inductance of a transformer depends on the permeability of the core.
☐	☒	One can shift an impedance from the primary of an ideal transformer to its secondary, by multiplying this impedance by n_1^2/n_2^2 where n_1 and n_2 are the number of turns at the primary and at the secondary respectively.
☐	☒	The efficiency of a transformer increases with the frequency.

Synchronous machines

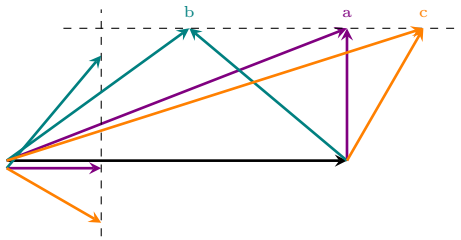
Question 3



The above schematic presents the Behn-Eschenburg model for one phase of a synchronous generator in star configuration. From this schematic, one has drawn the below phasor diagram for one particular operating point (a) of the synchronous generator.



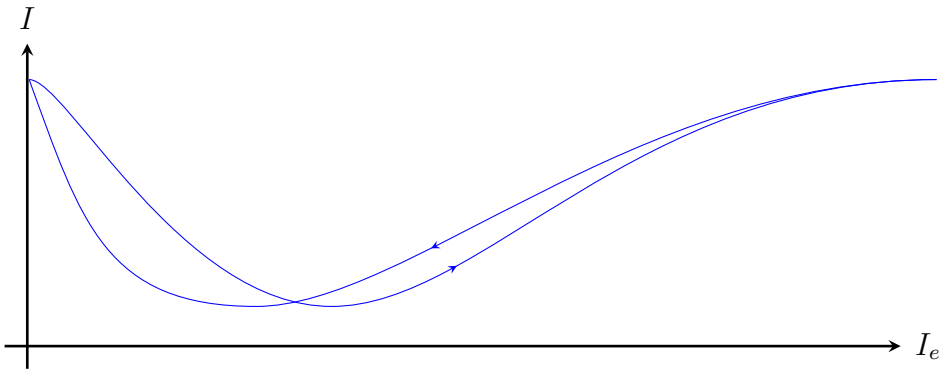
Answer:



If the output active power and the RMS output voltage are kept constant, complete the above phasor diagram for two other working points:

(b) the excitation current I_e is smaller than at the working point (a),
(c) the excitation current I_e is larger than at the working point (a).

From it, draw the evolution of the RMS output current I, as a function of the excitation current I_e. Start with a zero excitation current, increase it up to saturation, **and decrease it back to zero**. Indicate with arrows the direction of your curve and briefly explain its shape.



Answer:
When I_e decreases back, the entire curve shifts to the left due to hysteresis: for any given I_e, $E_v(I_e)$ on the descending branch is higher than it was at the same I_e during the ascending sweep.

Question 4

Draw the phasor diagram of a synchronous generator with negligible stator resistance, connected to a resistive-capacitive load. Define the electric angle of the machine and represent it on the diagram. Establish the formula giving the value of the torque of the machine as a function of the electric angle.

Answer: See theoretical classes

Draw a second phasor diagram in the no-load case. What is the value of the electric angle in this case?

Answer: See theoretical classes

Asynchronous machines

Question 5

Draw the circle diagram of an asynchronous machine and indicate on it, for a given slip $0 < g < 1$:

- the stator voltage $\bar{U}_1$ and current $\bar{I}_1$
- the magnetizing current $\bar{I}_\mu$
- the rotor current $\bar{I}'_2$

Prove that the rotor efficiency η_{rot} is bounded by $1 - g$.

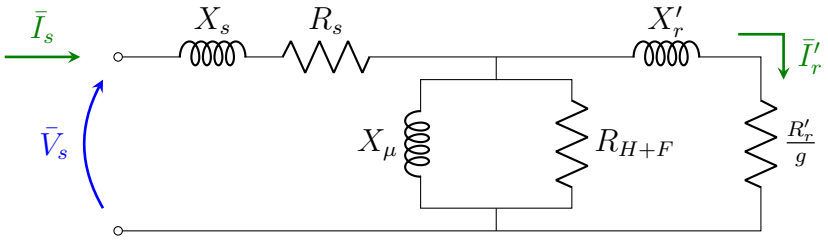
Answer: See theoretical classes

Redraw the diagram with associated voltages and currents if one

1. blocks the rotor ($\dot{\theta} = 0$)
2. doubles the frequency
3. doubles the frequency and the stator voltage

Answer: See theoretical classes

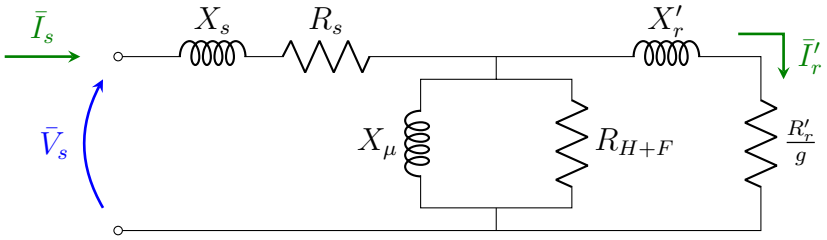
Question 6



The above schematic presents the one-phase equivalent electric circuit of a three-phase asynchronous motor in star configuration. This motor has three pairs of poles, and is powered at a frequency of 60 Hz.

The motor provides a mechanical torque C_{mec} of $\frac{300}{\pi}$ Nm at a slip g of 2 %. If the mechanical losses account for 294 W and $R'_r = 0.82\ \Omega$, what is the electromagnetic power P_{elm} for one phase of the equivalent circuit and what is the RMS current I'_r flowing through $\frac{R'_r}{g}$?

Answer: $P_{elm} = 4018$ W (for a single phase) and $I'_r = 10$ A



Considering the following impedance values:

$X_s = 3.5\ \Omega$, $R_s = 0.75\ \Omega$, $X_\mu = 102\ \Omega$, $R_{H+F} = 914\ \Omega$, $X'_r = 9.11\ \Omega$, and $R'_r = 0.82\ \Omega$,

what is the input RMS current I_s? **Do not neglect any component of the equivalent circuit.**

Note: If you were unable to find I'_r at the previous point, assume $I'_r = 10$ A.

Answer: $I_s = 12$ A

DC machines

Question 7

For each of the below affirmations, select if it is true (T) or false (F) (right +1, wrong -0.5, min. 0).

T	F	
☒	☐	The armature should be laminated to reduce eddy current losses.
☐	☒	The inductor should be laminated to reduce eddy current losses.
☒	☐	If there is no remanent magnetization, a shunt DC generator will not self-start.
☒	☐	A shunt DC motor will work just fine if it is fed with AC power.

Question 8

Draw the equivalent circuit of a DC motor with independent excitation. Explain the concept of armature reaction and give the meaning of the different terms in the following equation:

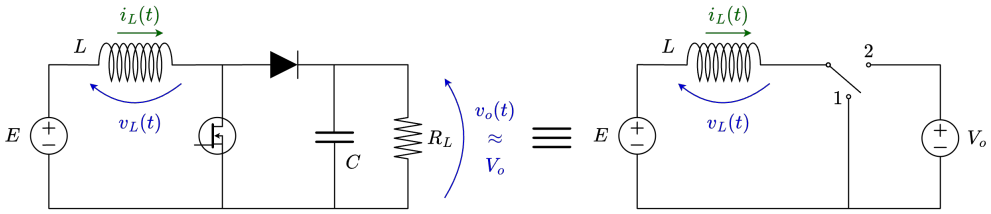
$$E = E_v - \psi(I_a) + R_a I_a$$

Answer: See theoretical classes

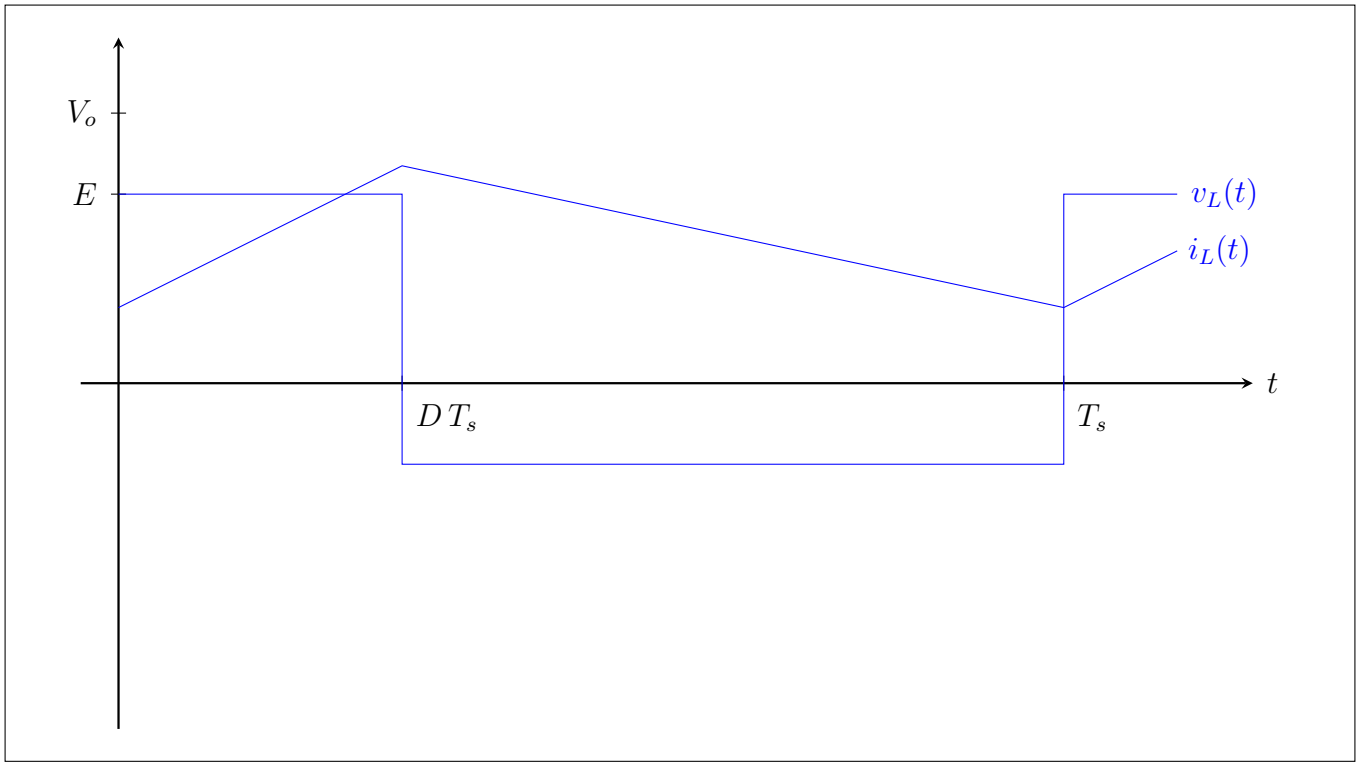
Electronic control systems

Question 9

The figure on the right presents a DC-DC boost converter.



Assuming D is the percentage of time the switch is in position 1 and $(1 - D)$ the percentage of time it is in position 2, draw the waveform of the voltage across the inductance ($v_L(t)$) in steady-state condition. Deduce from it the shape of the current waveform in the inductance ($i_L(t)$) and draw it on the same diagram using another color.



The converter is connected to a $24\,V$ battery and is controlled at a switching frequency $f = 2\,kHz$. With a duty cycle D of 30 %, what should be the value L of the inductor to obtain a current ripple of $100\,mA$?

Answer: $L = 18$ mH

Additional page – Use it if you run out of space for a question. If you do so, clearly notify it.

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