First name:

Last name:

Student #:

`ELEC0431` — **Electromagnetic Energy Conversion**
Written Exam

June 2022

You have 3 hours to complete this exam. Read the questions carefully and **answer each question, except multiple choices, on a separate sheet of paper**. You may answer in English or in French. **Do not forget to mention your name and the question number (Q1, Q3, Q5, Q6, Q8, Q10) on each sheet.** If you are stuck with one question, do not spend your entire time on it, but try to move to the next one. Even if you can (easily) find the final answer, justify your developments and explain your reasoning.

Calculators are allowed, but smartphones and connected watches are strictly forbidden.

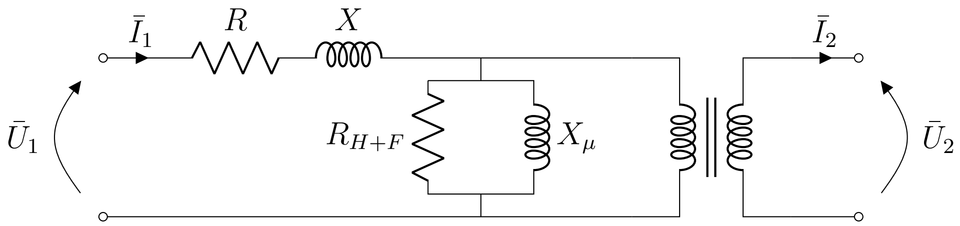
Bon travail !

Transformers

Q1. A single phase transformer is characterized experimentally. With the secondary winding short-circuited, the RMS current at the secondary is $I_{2s} = 15\,A$ for an input RMS current $I_{1s} = 1.5\,A$, an input RMS voltage $U_{1s} = 30.6\,V$ and a consumed power $P_{1s} = 45\,W$. The values $R_{H+F} = 5\,k\Omega$ and $X_\mu = 1\,k\Omega$ are also provided.

Considering the simplified equivalent model of the transformer given below:

1. Calculate the resistance R and the reactance X. Answer: $R = 20\,\Omega$, $X = 4.02\,\Omega$



A load composed of a resistor $R^\star$ in parallel with an inductor $L^\star$ is now connected at the output of the transformer. For an RMS input voltage of $220\,V$, an RMS input current of $0.4\,A$ out of phase by $\varphi = 44°$ is measured.

2. Calculate the resistance $R^\star$ and the inductance $L^\star$. Answer: $R^\star = 8.9\,\Omega$, $L^\star = 96\,\text{mH}$

Q2. For a perfect three-phase transformer operating at constant line input voltages and connected to a three-phase resistive load in configuration Δ, what configuration leads to the lower active power consumption?

- ☐ Y at primary and Y at secondary.
- ☐ Δ at primary and Y at secondary.
- ☒ Y at primary and Δ at secondary.
- ☐ Δ at primary and Δ at secondary.
- ☐ The configuration doesn't impact the active power consumption.

Synchronous machines

Q3. Consider the Behn-Eschenburg model of one phase of a synchronous generator characterized by a synchronous impedance $X_s = 4.3\,\Omega$ and negligible resistance R_s. A delta load composed of resistors $R = 6\,\Omega$ in series with capacitors $C = 270\,\mu F$ is connected at the output of the machine. Knowing that an output phase voltage of $115\,V$ is measured when no load is connected:

1. Taking the output phase voltage as the reference, compute the RMS value and phase angle of the phase current. Answer: $\bar{J} = 11.98\angle 51.3°$

2. Plot the phasor diagram.

Q4. A synchronous machine is connected to the power grid, with the rotation speed and the excitation current I_e of the machine tuned so that the stator and the grid voltages match in both amplitude and phase. We consider the machine as unsaturated, and we neglect the Joule losses in the stator windings. Starting in this state, select all the correct affirmations from the list below:

- [x] The machine does not exchange any power with the grid.
- [x] All other things kept equal, if I_e is increased then the machine will inject reactive power in the grid.
- [x] All other things kept equal, if the mechanical torque driving the machine is increased then the machine will inject active power in the grid.
- [x] All other things kept equal, if the mechanical torque driving the machine is increased then the machine will receive reactive power from the grid.

Q5. Derive the torque formula as a function of the electric angle.

Asynchronous machines

Q6. Considering that the 2-pair-of-pole asynchronous motor of the laboratories is powered at the stator by the three-phase RMS line voltages $U_1 = 225\,V$; that the RMS stator current measured for each phase is $I_1 = 15\,A$; and that the mechanical power and mechanical torque are respectively $P_m = 5480\,W$ and $C_m = 35.15\,Nm$:

1. What is the slip g of the asynchronous motor ? Answer: $0.749\,\%$

2. Why is the motor started in one configuration (Y or Δ) and then switches to the other? Why does it help (give a numerical value)?

Q7. We want to control the speed of a squirrel cage asynchronous motor. Select all the possible methods for doing so in the list below:

- [ ] By modifying the rotor resistance.
- [x] By modifying the stator voltage.
- [x] By modifying the power supply frequency.

DC machines

Q8. A shunt-connected DC generator driven by a diesel engine supplies a current of $25\,A$ to a $110\,V$ battery. The armature and field resistances are $0.5\,\Omega$ and $110\,\Omega$ respectively, and the friction, windage and other losses total $220\,W$.

1. Calculate the generated EMF. Answer: $E = 123\,\mathrm{V}$
2. Calculate the efficiency. Answer: $\eta = 80.46\,\%$

Q9. Among the following propositions, select all the correct ones:

- ☐ Compared to the other studied motors, the DC motors are the only ones which do not use laminated cores.
- ☒ A DC generator can be used as a DC motor but the performance decreases.
- ☐ Considering the setup of the DC laboratory in the stable regime, decreasing the load resistance increases the speed of rotation.
- ☒ Considering the setup of the DC laboratory in the stable regime, decreasing the excitation current of the DC generator increases the speed of rotation.
- ☐ When the DC generator is connected in shunt, decreasing too much the load resistance makes the machine stop rotating.

Power electronic converters

Q10. Consider a boost converter without losses such as depicted hereunder. Knowing that the input voltage is $V_{in} = 70\,V$, that the output voltage is $V_{out} = 340\,V$, that the inductor is $L = 570\,mH$, that ripples in the inductance current are $\Delta I_L = 0.1\,A$ and that the switching frequency is $f_s = 488\,Hz$ and considering that the converter operates under steady-state conditions, compute the switching frequency (in Hz) required to obtain an inductance current ripple of $0.07\,A$.

Answer: $f_s = 697.14\,\mathrm{Hz}$