ER66 FINAL EXAM

14 janvier 2025 de 16h30 à 18h30 en salle P305 à Sevenans

The use of lecture notes is not allowed.
You can reply either in English or in French.
Use of programmable calculators is not allowed.

Exam Instructions for Students

The exam consists of **two sections**, **Section A** and **Section B**, with the following requirements:

1. **Section A**:
   - You must solve **any 2 out of the 3 questions** in this section.
   - The total marks for Section A are **12**.
   - If you choose to solve all three questions, **only the two highest-graded answers** will be counted, and the lowest-graded answer will be disregarded.
2. **Section B**:
   - You must solve **all 2 questions** in this section.

Submission Requirements:

- The answers to **Section A** and **Section B** must be written on **separate sets of sheets**, as they will be assessed by **different teachers**.
- Ensure that you clearly write your **name and surname** and sign each sheet in both sets.

Important: Strictly comply with this rule. Failure to separate answers as instructed may result in delays or issues with the evaluation process.

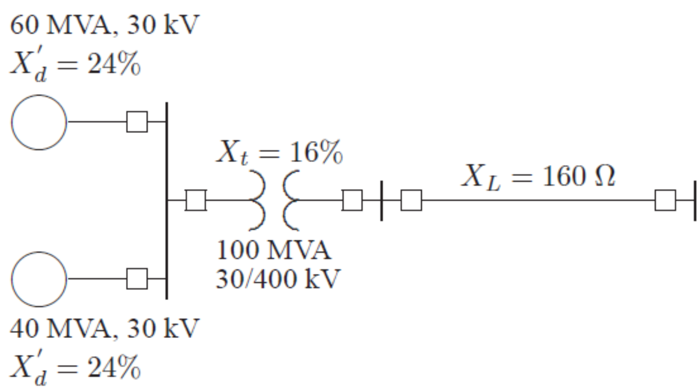
Thank you for your cooperation, and best of luck on your exam!

SECTION A

QUESTION 1 (6 MARKS)

The system shown in the figure below is initially on **no load** with generators operating at their rated voltage with their emfs in phase. The rating of the generators and the transformers and their respective percent reactances are marked on the diagram. All resistances are neglected. The line impedance is $j160\Omega$. A three-phase balanced fault occurs at the receiving end of the transmission line.

a) Determine the per-unit (pu) values for the circuit, using a power base of 100 MVA and a voltage base of 400 kV for the line section. **(1.5 mark)**
b) Calculate the symmetrical (three-phase) solid short-circuit current in the circuit by using the Thévenin's theorem. **(3 marks)**
c) Compute the short-circuit capacity (SCC) and explain why, in general (so not in connection with this exercise) a low SCC indicates that the grid is weak **(1.5 mark)**



Hint: Recall
1) that the product of the ***pre-fault*** *bus voltage and the* ***post-fault current*** *is referred to as* ***short-circuit capacity (SCC)****. By definition, it has the value*

$$|SCC| \triangleq \sqrt{3}|V||I^f|\ MVA$$

Where V is the line-to-line pre-fault bus voltage

2) that the circuit is operating under no-load conditions, with both generator voltages having an amplitude of 1 per unit (pu) and being in phase. As a result, no current flows between the generators or through the transmission line.

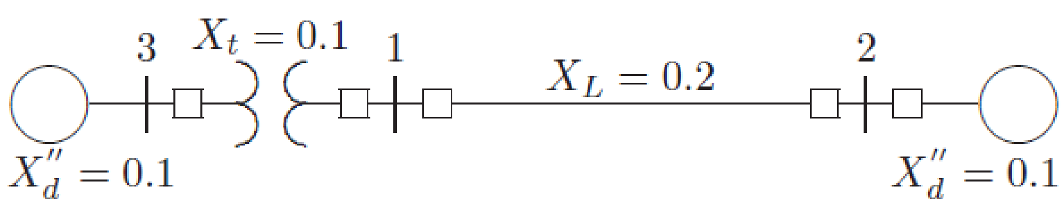
QUESTION 2 (6 MARKS)

The one-line diagram of a simple power system is shown in the figure below. Each generator is represented by an emf behind the transient reactance. All impedances are expressed in per unit on a common MVA base. All resistances and shunt capacitances are neglected. The generators are operating on **no load** at their rated voltage with their emfs in phase.

A three-phase fault occurs at bus 1 through a fault impedance of $Z_f = j0.08$ per unit.

(a) Using Thévenin's theorem obtain the impedance to the point of fault and the fault current in per unit. **(3 marks)**

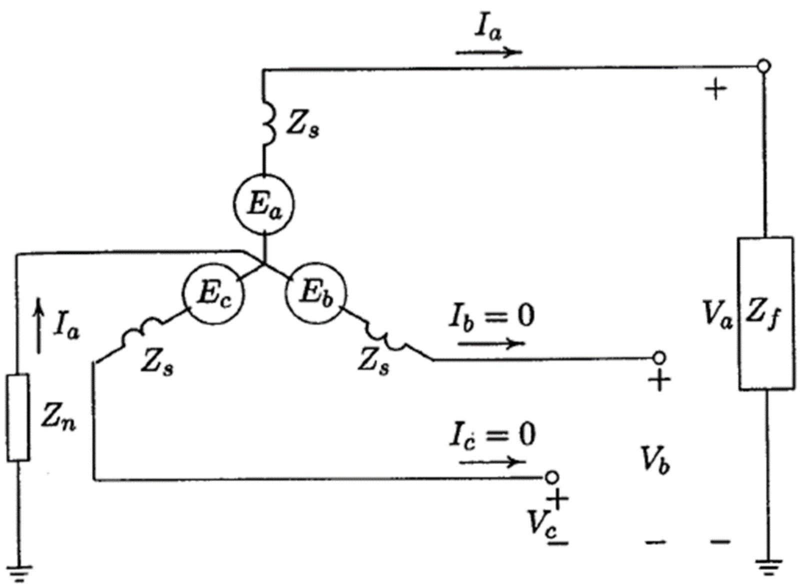
(b) Determine the bus voltages and line currents during fault. **(3 marks)**



Hint: Note that the circuit is operating under no-load conditions, with both generator voltages set at an amplitude of 1 per unit (pu) and in phase. Consequently, no current flows between the generators or through the transmission line. Based on this, the pre-fault voltage at Bus 1 can be understood directly without requiring any calculations.

QUESTION 3 (6 MARKS)

By using the symmetrical components (e.g. the Fortescue Theorem), calculate the single line-to-ground fault as shown in the figure below (assume the phase a as the phase affected by the fault). Also, explain how the positive, negative and zero-sequence circuits should be connected.



Line-to-ground fault on phase a.

SECTION B

QUESTION 4 (4 marks). Each question is worth 2/3 marks)

Here are multiple-choice quiz questions, select the right answers for each.

Q1: Which reactance's representing the subtransient reactance of the synchronous generator?

A. X_d
B. $X_d^{'}$
C. $X_d^{''}$
D. $X_q^{''}$

Q2: Which time constant representing the transient time constant of the synchronous generator?

A. T'_{do}
B. T'_{qo}
C. T'_d
D. T'_q

Q3: In a synchronous generator, what is the relationship between EMF (E) and magnetic induction (B)?
A. $E \propto B^2$
B. $E \propto \frac{1}{B}$
C. $E \propto B$
D. $E \propto B^{1/2}$

Q4: Which of the following operations represents an overexcited synchronous machine?
A. Supplies reactive power to the grid
B. Absorbs reactive power from the grid
C. Operates at unity power factor
D. Operates without load

Q5: What is the primary purpose of an Automatic Voltage Regulator (AVR) in a synchronous machine?
A. Control the frequency of the output voltage
B. Maintain constant power output
C. Regulate the field voltage to control terminal voltage
D. Monitor rotor speed fluctuations.

Q6: What protective function is used to detect the loss of excitation in a synchronous generator?
A. Overcurrent relay (51G)
B. Impedance relay (40G)
C. Reverse power relay (32R)
D. Differential relay (87G)

QUESTION 5 (4 marks)

A three-phase synchronous generator has the following specifications and conditions:

- Rated Power: 500 MVA
- Rated Voltage: 20 kV
- Reactances:
- $X_d = 1.1pu$
- $X_d^{'} = 0.24pu$
- $X_d^{''} = 0.15pu$
- The stator voltage operates at 5% above the nominal value before the fault.
- A three-phase short circuit occurs at the generator terminals.

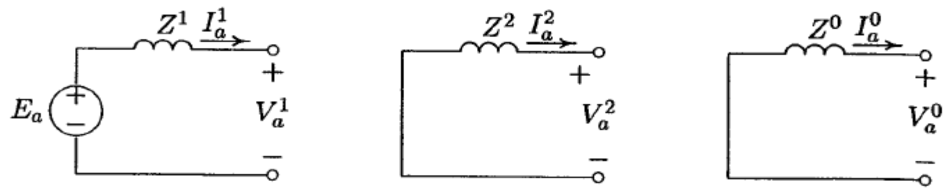
Tasks:

1. Calculate the **subtransient** short-circuit current at the generator terminals in:
   - Per-unit values **(0.5 marks)**
   - kA **(0.5 marks)**
2. If this generator feeds a motor with reactance $X_m^{''} = 0.20pu$ through a transformer and a distribution line with combined reactance $X_T = 0.305$pu :
   - Draw the single-line diagram of the system for same short circuit fault. (**2 marks**)
3. Calculate the total subtransient short-circuit current in:
   - Per-unit values **(0.5 marks)**
   - kA **(0.5 marks)**

APPENDIX

SEQUENCE IMPEDANCES OF SYNCHRONOUS MACHINE: unsymmetrical load

$$V_a^0 = 0 - Z^0 I_a^0$$
$$V_a^1 = E_a - Z^1 I_a^1$$
$$V_a^2 = 0 - Z^2 I_a^2$$



Sequence networks: (a) Positive-sequence; (b) negative-sequence; (c) zero-sequence.

FORTESCUE's THEOREM

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_a^0 \\ I_a^1 \\ I_a^2 \end{bmatrix}$$

$$\begin{bmatrix} I_a^0 \\ I_a^1 \\ I_a^2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_a^0 \\ V_a^1 \\ V_a^2 \end{bmatrix}$$

$$\begin{bmatrix} V_a^0 \\ V_a^1 \\ V_a^2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$