Faculty of Applied Sciences
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ELEC0431
Electromagnetic energy conversion

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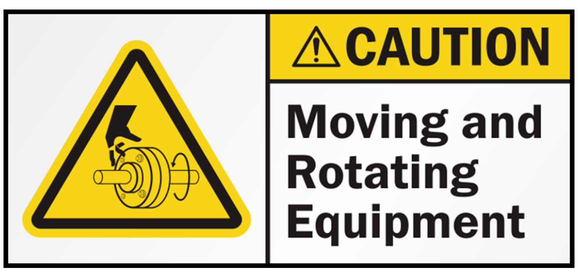
Laboratory 2: Synchronous machines

WARNINGS:

This laboratory involves high currents and voltages, think before acting !

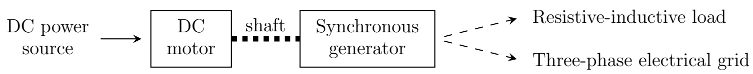


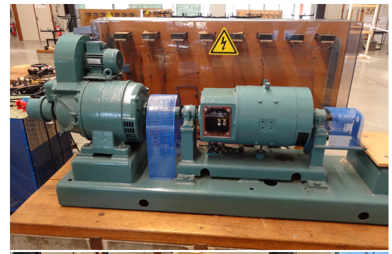
Keep your hands away from the rotating shafts and TIE LONG HAIR !

Contents:

1 Components

A DC motor, powered by an external DC power source, brings the rotor of a three-phase synchronous generator to rotate.





The output of the three-phase synchronous generator can be connected to a balanced three-phase load. It consists of a resistive load in series with an inductive load.


Resistive load

A rotary switch on the front of the resistive load allows to select its value:

- position 0 $\rightarrow$ open circuit,
- position 1 $\rightarrow$ 36 Ω,
- position 2 $\rightarrow$ $\frac{36}{2}$ Ω,
- position 3 $\rightarrow$ $\frac{36}{3}$ Ω,
- etc.

A wheel on top of the inductive load allows to vary its value. Note that one every two contacts is left in open circuit to avoid any large current to suddenly appear when turning the wheel, as it would otherwise connect two branches of the load in parallel.


Inductive load

To connect a "purely" inductive load to the generator's output, the resistors should be manually short-circuited. In the other hand, it is not possible to connect a "purely" resistive load to the generator's output. Instead, simply set the inductive load to its minimum value.

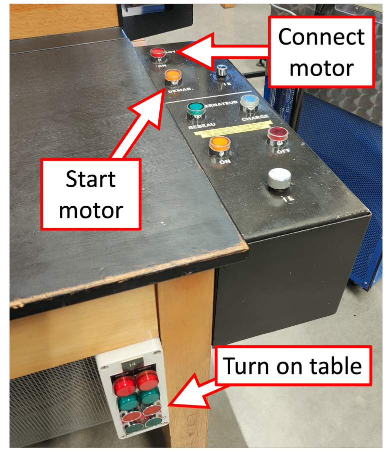
The output of the three-phase synchronous generator can also be connected to a three-phase electrical grid. To perform the connection, the synchronous generator and the grid **MUST**:

1. have the same order of phases,
2. share the same voltage amplitude,
3. have identical frequency,
4. be in phase.

Connecting the generator to the grid without filling any of these four conditions can severely harm the generator. The generator was wired with careful attention to phase order. Voltage, phase, and frequency comparators are used to fulfill the three remaining conditions.

2 Start-up

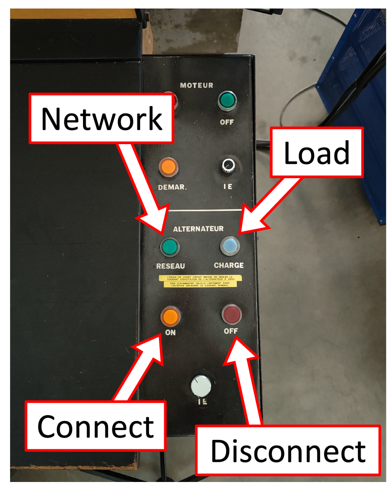
1. Turn on the table by pressing the red buttons next to the table right leg.
2. Connect the DC motor to the external DC power source.
3. Start the DC motor. It will start in 2 audible steps by progressively increasing the DC motor input voltage.
4. You can increase (resp. decrease) the speed of rotation by decreasing (resp. increasing) the excitation current of the DC motor.



By default, the output of the synchronous generator is left in open-circuit. It can be connected to the resistive-inductive load or to the three-phase electrical grid.

Connection to the resistive-inductive load:

1. Press "CHARGE" (load).
2. Press "ON".
3. Disconnect by pressing "OFF".



Connection to the grid:

1. Press on "RESAEU" (network). This will activate the voltage, phase and frequency comparators.
2. **Make sure the grid and the generator output share the same voltage amplitude, frequency and phase. Call an assistant to do it with you.**
3. Press on "ON".
4. Before disconnecting, **ensure the output power is null** and press "OFF".

3 Questions

3.1 Question 1

What are the current, voltage and power ratings of the three-phase synchronous generator and of the DC motor?

Hint: You will find all the information written on the nameplates on the machines.

You should not exceed those ratings for the rest of the lab. Additionally, the current in the cables cannot surpass 10 A.

3.2 Question 2

With a fixed excitation current flowing through the rotor's winding of the three-phase synchronous generator, and keeping its outputs open-circuited, measure how the output voltage varies with the speed of rotation and discuss the underlying principle that explain this behavior.

3.3 Question 3

Keeping the outputs of the three-phase synchronous generator open-circuited, bring its rotor to its nominal speed of rotation. Measure, draw and explain the no-load characteristic.

Hint: Take measurements of the excitation current and of the output voltage starting with a zero excitation current and increasing it to reach the nominal output voltage. Later, do the same decreasing it back to zero.

3.4 Question 4

If the ferromagnetic materials remain unsaturated, one phase of the three-phase synchronous generator can be represented using the Behn-Eschenburg model. Draw this model, explain what the impedances R and X_s stand for, and give an expression for the no-load output voltage E_v.

3.5 Question 5

In the theoretical class, one makes the hypothesis $X_s \gg R$ so that R can be neglected. Using this hypothesis, draw a phasor diagram that represents the condition of a purely resistive load connected to the output of the three-phase synchronous generator and deduce from it the theoretical relationship between output voltage and output current.

Do the same for a purely inductive and a purely capacitive load.

3.6 Question 6

Measure the U-I output characteristic of the three-phase synchronous generator when it is connected to the resistive load (inductive load to its minimum) and when its is connected to the inductive load (resistive load shorted, **call an assistant to put and remove the shorts**).

Hint: Keep the speed of rotation constantly to its nominal value and start with an open-circuit output line voltage of 70 V. Gradually decrease the load impedance and ***make sure not to overpass an output current of 10 A****. It is not required to make a short-circuit measurement.*

Do your measurements match the theoretical curves obtained at Question 5?

3.7 Question 7

What are the four requirements needed to safely and smoothly connect a three-phase synchronous generator to the three-phase electrical grid?

What would be the individual repercussions if each of the four requirements were not met when connecting the generator to the grid?

Call an assistant to help you connect the generator to the grid.

3.8 Question 8

With the generator connected to the grid, what happens when you change the DC motor excitation current? Why?

3.9 Question 9

With the generator connected to the grid, increase the DC motor excitation current until the synchronous generator's output power gets negative. Why is it negative? How does the synchronous machine now acts like? How about the DC motor?

3.10 Question 10

Using the Behn-Eschenburg model obtained at Question 4 with neglected resistance R, draw a phasor diagram showing the no-load phase voltage $\bar{E}_v$, the output phase voltage $\bar{V}$, the output phase current $\bar{J}$ and the voltage drop $\bar{V}_{X_s}$ across the synchronous reactance X_s, assuming a phase lag φ of approximately 30°.

What are the two conditions to measure the V-curve (also called Mordey curve) of a three-phase synchronous machine? How does these two conditions translate to your phasor diagram?

Redraw approximately the phasor diagram at three working points fulfilling these conditions:

(a) the current J is minimum,
(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).

Based on these three phasor diagrams, draw a theoretical V-curve, labeling appropriately the axes of the diagram, and place the working points (a), (b) and (c) on it. From this curve, explain how one can compensate the total reactive power on the three-phase electrical grid.

What happens to the V-curve if it is measured with a higher output active power and with a null output active power?

3.11 Question 11

Measure the V-curve. Does it match the one derived theoretically at Question 10? What happens for large excitation currents?