Faculty of Applied Sciences
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ELEC0431
Electromagnetic energy conversion

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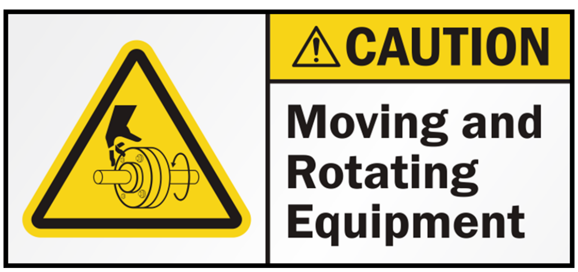
Laboratory 3: Asynchronous machines



WARNINGS:

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

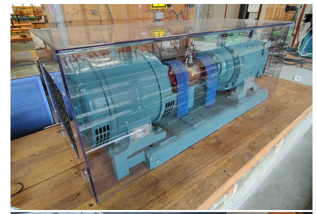
Keep your hands away from the rotating shafts and TIE LONG HAIR !

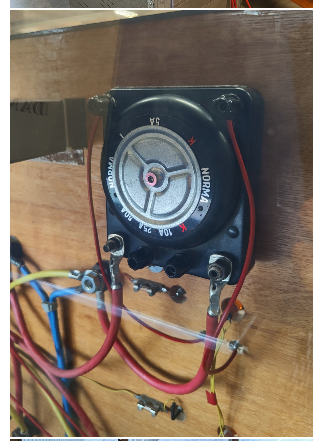
Contents:

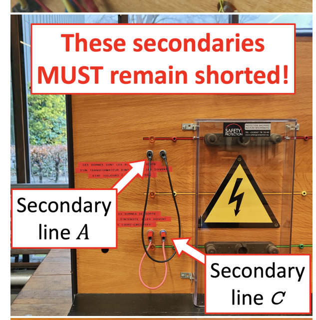
1 Old asynchronous machine

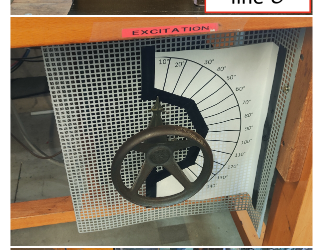
1.1 Components

An asynchronous motor will be studied. Its rotor is linked to the one of a DC generator connected to a resistive load. The DC generator therefore acts like a variable mechanical load.









Three-phase electrical grid → Three-phase autotransformer → Curr. transfo. → Three-phase async. motor ⋯ Shaft ⋯ DC generator → Resistive load

A three-phase autotransformer, whose primary is connected to the three-phase electrical grid, delivers secondary line voltages of adjustable amplitude: turn the rotary switch on top of it to increase or decrease it. The autotransformer secondary is connected to the input of the three-phase asynchronous motor.

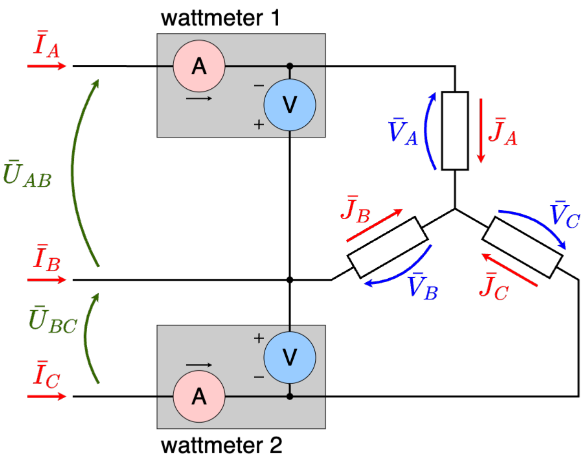
To measure the total three-phase active and reactive power consumed by the three-phase asynchronous motor, one can use the two-wattmeter method (see Section 1.2). To do so, it is necessary to measure the input line currents flowing through lines A and C. However, these currents may exceed the measurement range of conventional ammeters. Therefore, current transformers are used, with their primary windings connected in series with line A and line C. They decrease the currents by a factor $n = 10$ (so that conventional ammeters can be used) and, inversely, increase the voltage by a factor $n = 10$. These current transformers are visible at the back of the table and their secondaries are accessible in the front of the table.

Note that, for currents to flow in line A and line C, **the secondaries of these current transformers must remain shorted**. Furthermore, if they are left open, very high voltages can appear at their secondary terminals as it would be 10 times larger than their primary voltage (up to 10×240 V). Additionally, **DO NOT EVER unplug the shorts when a current is flowing**. This could create electric arcs and cause severe injuries.

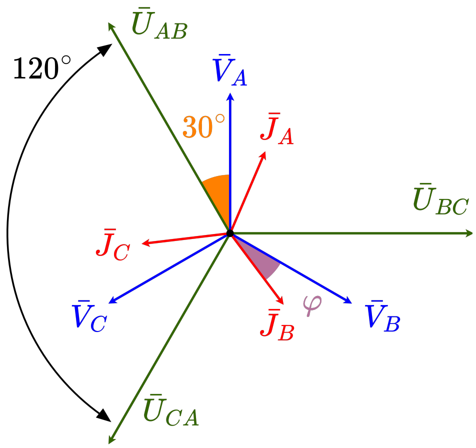
The DC generator is used to apply a torque to the three-phase asynchronous motor. To increase it, one should increase the active power consumed by the DC motor. This can be done in two distinct ways:

1. Increase the DC generator output voltage by increasing its excitation current. To do so, turn clockwise the wheel situated under the table (angle values have no physical meaning, they are used as simple indications).
2. Decrease the resistance of the load. Its value can be selected with the rotary switch at its front:
   - position 0 → open circuit,
   - position 1 → $\frac{36}{1}$ Ω,
   - position 2 → $\frac{36}{2}$ Ω,
   - etc.

1.2 Two wattmeter method



Two wattmeters can be used to compute the total active and reactive powers of a three-phase system. The first wattmeter measures the current flowing in the first line ($\bar{I}_A$) and the voltage from the first to the second line ($\bar{U}_{BA} = -\bar{U}_{AB}$). The second wattmeter measures the current flowing in the third line ($\bar{I}_C$) and the voltage from the third to the second line ($\bar{U}_{BC}$).



In this configuration, the voltages and currents can be represented on a phasor diagram. Taking $\bar{U}_{BC}$ as the reference, $\bar{U}_{AB}$, $\bar{U}_{BC}$, $\bar{J}_A$ and $\bar{J}_C$ can be expressed as:

- $\bar{U}_{AB} = U\ e^{j\,120°}$,
- $\bar{U}_{BC} = U$,
- $\bar{J}_A = I\ e^{j\,(120°-30°-\varphi)} = I\ e^{j\,(90°-\varphi)}$,
- $\bar{J}_C = I\ e^{j\,(-120°-30°-\varphi)} = I\ e^{j\,(-150°-\varphi)}$.

For the first wattmeter, the complex power S_1 measured is:

$$S_1 = -\bar{U}_{AB}\,\bar{J}_A^* = -U\ e^{j\,120°}\ I\ e^{-j\,(90°-\varphi)} = -U\ I\ e^{j(\varphi+30°)}$$

while, for the second wattmeter, the complex power S_2 measured is:

$$S_2 = \bar{U}_{BC}\,\bar{J}_C^* = U\ I\ e^{-j\,(-150°-\varphi)} = U\ I\ e^{j\,(180°-30°+\varphi)} = -U\ I\ e^{j(\varphi-30°)}.$$

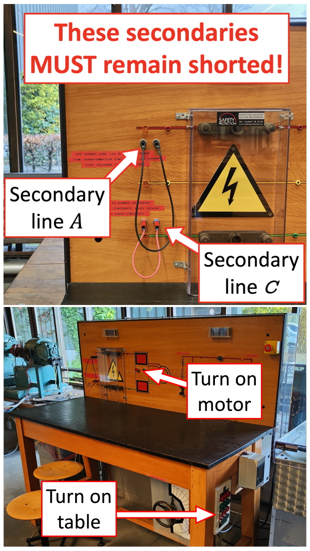
By taking $-(P_1+P_2)$, the total active power is obtained:

$$\begin{aligned}-(P_1+P_2) &= \mathbb{R}\{-S_1\} + \mathbb{R}\{-S_2\} = \mathbb{R}\{-S_1 - S_2\} = U\,I\,\mathbb{R}\{e^{j(\varphi+30°)} + e^{j(\varphi-30°)}\}\\ &= U\,I\,\mathbb{R}\{e^{j\varphi}\,(e^{j\,30°} + e^{-j\,30°})\} = U\,I\,\mathbb{R}\{e^{j\varphi}\,\sqrt{3}\} = U\,I\,cos(\varphi)\,\sqrt{3} = 3\,V\,I\cos(\varphi) = P_{3\varphi}.\end{aligned}$$

By computing $\sqrt{3}(P_1-P_2)$, the total reactive power is obtained:

$$\begin{aligned}\sqrt{3}\,(P_1-P_2) &= \sqrt{3}\,(\mathbb{R}\{S_1\} - \mathbb{R}\{S_2\}) = \sqrt{3}\,\mathbb{R}\{S_1 - S_2\} = \sqrt{3}\,U\,I\,\mathbb{R}\{e^{j(\varphi-30°)} - e^{j(\varphi+30°)}\}\\ &= \sqrt{3}\,U\,I\,\mathbb{R}\{e^{j\varphi}\,(e^{-j\,30°} - e^{j\,30°})\} = \sqrt{3}\,U\,I\,\mathbb{R}\{e^{j\varphi}\,e^{-j\,90°}\} = \sqrt{3}\,U\,I\,sin(\varphi)\\ &= 3\,V\,I\sin(\varphi) = Q_{3\varphi}.\end{aligned}$$

1.3 Start-up



1. **Double check that the current transformer secondaries are shorted.** Note that you can use ammeters to perform the shorts and measure the currents, thanks to their really low internal impedance.
2. Turn on the table by pressing the red buttons next to the table right leg.
3. Turn on the asynchronous motor by pressing the red button on the board. You can turn the motor off by pressing the green button.
4. Increase the input voltage by turning the black indicator on top of the autotransformer.

1.4 Questions

1.4.1 Question 1

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

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

1.4.2 Question 2

Based on the information provided on the nameplates, what is:

- the nominal speed of rotation of the asynchronous motor,
- the synchronous speed of rotation of the asynchronous motor,
- the slip of the asynchronous motor at nominal operating point,
- the torque of the asynchronous motor and of the DC generator at nominal operating point?

Do not exceed a torque of 35 Nm. Both the asynchronous motor and the DC generator can handle higher torque, but the shaft is weaker. You can read the torque on the display on the top right of the panel. The speed of rotation is given on the top left.

1.4.3 Question 3

Draw the simplified equivalent model of one phase of the three-phase asynchronous motor and explain what each of the impedances $X_s, R_s, X_\mu, R_{H+F}, X'_r$ and $\frac{R'_r}{g}$ stands for. Decompose the term $\frac{R'_r}{g}$ in two to support your explanation.

1.4.4 Question 4

When turning on the three-phase asynchronous motor, the motor is initially wired in a star configuration but rapidly switches to a delta configuration. How does the configuration impact the input line current? Therefore, why is the configuration changed when switching on the motor?

1.4.5 Question 5

Considering the equivalent model from Question 3, for which impedances can you determine values through an open-circuit measurement assuming $X_s, R_s, X'_r, R'_r \ll R_{H+F}, X_\mu$? Perform the open-circuit measurement and deduce the appropriate impedance values.

Hint: We reach an open-circuit condition when the speed of rotation is equal to the synchronous speed, so that the slip g is 0. To get as close as possible from this condition, set the input voltage to its maximum and leave the DC generator open-circuited.

Hint: Remember to consider the current transformers in your calculations. The actual currents and active powers are 10 times greater than the readings indicate.

1.4.6 Question 6

Considering the equivalent model from Question 3, perform the short-circuit measurement and compute $R_s + R'_r$ and $X_s + X'_r$, assuming $X_s, R_s, X'_r, R'_r \ll R_{H+F}, X_\mu$.

Hint: Short circuit tests on three-phase asynchronous motors are usually performed by blocking the rotor so to force it to be motionless and therefore have a slip g of 1. Here, it is impossible to proceed this way due to the plastic protection around the machines. A workaround is to set the input voltage sufficiently low to ensure the motor cannot overcome friction and stays still. Place yourself at the limit (a slight increase in the input voltage would make the motor rotate) to take your measurements.

Hint: Remember to consider the current transformers in your calculations. The actual currents and active powers are 10 times greater than the readings indicate.

Hint: The wattmeters read line currents, how do you translate those to phase currents?

Do you respect the hypothesis $X_s, R_s, X'_r, R'_r \ll R_{H+F}, X_\mu$?

1.4.7 Question 7

Measure the three-phase asynchronous motor efficiency at a torque of 35 Nm.

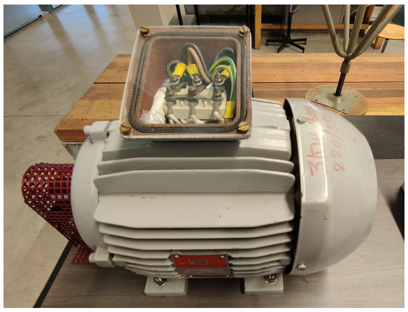
Do not exceed a torque of 35 Nm as a higher torque could damage the shaft. Pay particular attention when turning the wheel to increase the DC generator excitation current, this latter first very slowly increases but suddenly rises.

2 New asynchronous machine

2.1 Components

In this laboratory, the studied asynchronous motor is not directly connected to a three-phase power grid. Instead, it is powered by the `UMV 4301` speed controller which turns the one-phase power provided by the domestic electrical grid into a three-phase power to drive the asynchronous machine.

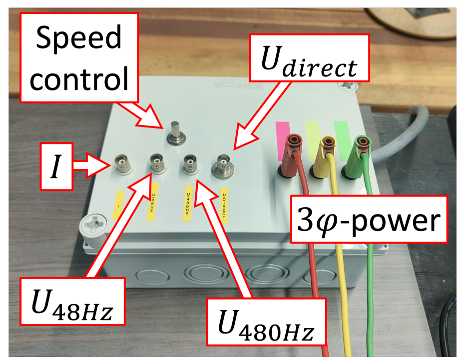
The studied asynchronous machine



The `UMV 4301` speed controller

An electrical box connects the speed controller to the asynchronous motor. In particular, the yellow, green and red banana connectors hold the three-phase voltages generated by the speed controller and supplying the asynchronous motor. **Do not unplug them if the table is on.**

A knob allows to control the speed of the asynchronous motor. Turn it clockwise to increase the speed. **Do not modify the speed directly on the speed controller.**



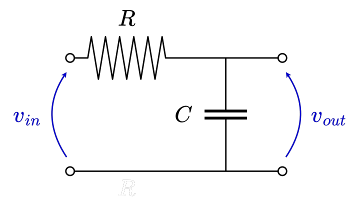
Four coaxial connectors allow to measure the following signals:

- U_{direct}: The voltage between the line B and the line A ($u_{BA}(t) = -u_{AB}(t)$).
- U_{480Hz}: The voltage U_{direct} processed by a low-pass filter of cutoff frequency $f_c = 480\,Hz$.
- U_{48Hz}: The voltage U_{direct} processed by a low-pass filter of cutoff frequency $f_c = 48\,Hz$.
- I: The current flowing in the line B ($i_B(t)$).

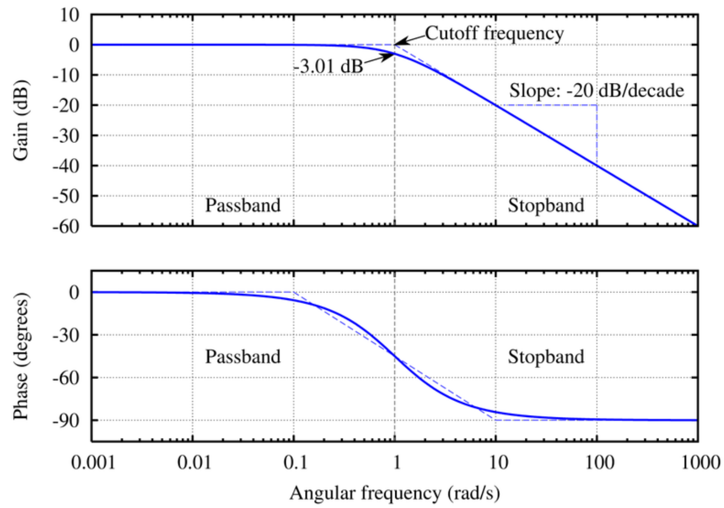
One can visualize these signals using an oscilloscope.

2.2 RC low-pass filters

The basic low pass filter is an RC circuit used to filter all frequencies higher than the specified cutoff frequency. In the circuit here on right, the cutoff frequency is given by $f_c = \frac{1}{2\pi RC}$.

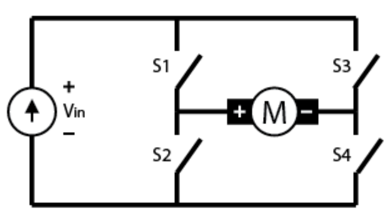


This low-pass filter reduces high-frequency components but also introduces a phase shift (see figure below).



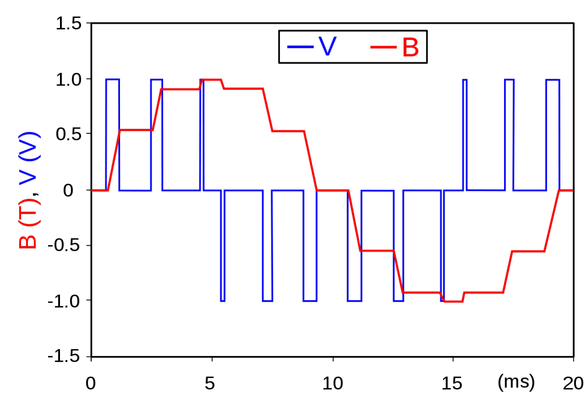
2.3 H-bridges

The basic operating principle of the speed controller can be understood by considering H-bridges which are electrical circuits used to drive motors. The figure below introduces their functioning:



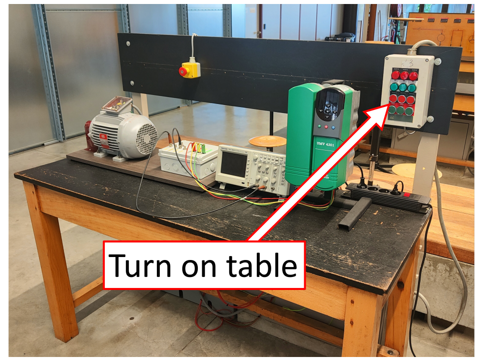
Switch configuration				voltage at M
S_1	S_2	S_3	S_4	
closed	open	open	closed	$V_M > 0$
open	close	close	open	$V_M < 0$
open	open	open	open	$V_M = 0$

Switches are controlled to drive a positive, negative or no voltage through the motor. It allows to create pulsed signals which are smoothed directly by the motor. For instance, the graph on right is obtained by considering a perfect inductor. In this condition, the magnetic flux density $B(t)$ is directly proportional to the integral of the voltage over time. By playing with the voltage sign and with the width of the pulses, the magnetic field evolution can take the shape of a sinusoidal curve. This technique is called "pulse width modulation" or PWM in the abbreviated form.



2.4 Start-up

To turn on the table, press the red buttons above the table. The machine will start as soon as the buttons are pressed. To turn the table off, press the green buttons.



2.5 Questions

2.5.1 Question 1

In which configuration is the three-phase asynchronous motor wired?

Hint: A small transparent window on the motor provides a clear view of the cable connections.

What are the current, voltage and power ratings of the three-phase asynchronous motor?

2.5.2 Question 2

Show on the oscilloscope the signals U_{direct} and I. Can you link the two?

2.5.3 Question 3

What is the switching frequency.

Hint: The oscilloscope has functionalities to help you measuring time intervals. In particular, the button "cursor" allows to place two cursors and to measure the time interval between them; the "run/stop" button allows to freeze the screen and the trigger is used to stabilize the signal.

2.5.4 Question 4

Measure the peak-to-peak voltage you obtain on U_{48Hz} and U_{480Hz} for a speed of 500 RPM, 1000 RPM, 2000 RPM and for the nominal speed. How does the tension evolve with respect to the speed of rotation? How can you explain the difference between the measurements on U_{48Hz} and U_{480Hz}?

Hint: Measuring a peak to peak voltage is easily performed on the oscilloscope using the "measure" button.

2.5.5 Question 5

Make the machine rotate at its nominal speed and compare the two signals $U_{480\,Hz}$ and $U_{48\,Hz}$. What are the differences between the two? How can you explain these differences?

2.5.6 Question 6

Assuming the current lags the voltage, draw a phasor diagram showing the phase voltages $\bar{V}_A, \bar{V}_B, \bar{V}_C$, the line voltages $\bar{U}_{AB}, \bar{U}_{BC}, \bar{U}_{CA}$, the phase currents $\bar{J}_A$, $\bar{J}_B$, $\bar{J}_C$ and the line currents $\bar{I}_A, \bar{I}_B, \bar{I}_C$.

In this phasor diagram, depict the voltage $\bar{U}_{BA}$ (observable via the oscilloscope), the current $\bar{I}_B$ (also measurable with the oscilloscope), the phase shift φ between the phase current and phase voltage of one of the phases, and the phase lag θ measured between $\bar{I}_B$ and $\bar{U}_{BA}$. Deduce from it the relation linking φ and θ.

At the nominal speed of rotation, measure the phase angle φ. Can you make this measurement with the signal U_{480Hz}? Can you do it with the signal U_{48Hz}?

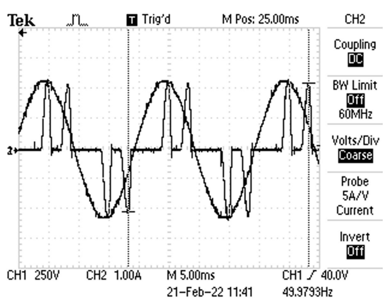
Compare the value of φ you measured with the one displayed on the machine nameplate. Are you close from it ? Why?

2.5.7 Question 7

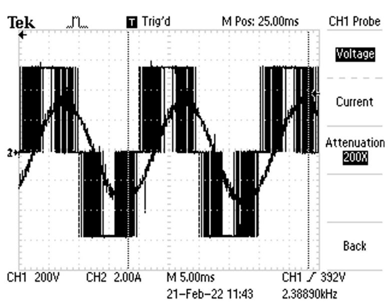
How would you proceed to reverse the direction of rotation of the machine. Present your solution to a teaching assistant before experimenting it.

2.5.8 Question 8

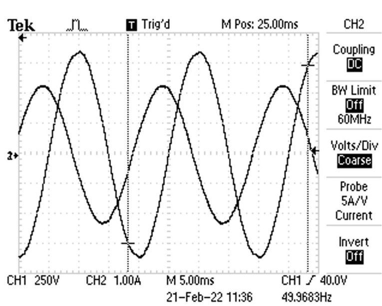
Three graphs have been plotted from the oscilloscope. For each of these graphs, which curve is the current, which one is the voltage? Why?



Voltage and current at the input of the speed controller.



Voltage and current at the output of the speed controller.



Phase voltage and corresponding phase current at the input of an asynchronous machine powered by a three-phase power supply.