Electromagnetic Energy Conversion ELEC0431

Exercise session 4: Three-phase transformers

3 March 2023

Florent Purnode (florent.purnode@uliege.be)

Montefiore Institute, Department of Electrical Engineering and Computer Science, University of Liège, Belgium

In this class…

- Reminder doodle laboratory sessions
- Exercise 9

Reminder doodle laboratory sessions

To create the laboratory schedule, you are required to fulfil the doodle "Group-of-4_ELEC0431_lab_schedule" by group of four students.

- Create a group of four students.
- Fulfil the doodle **with at least six available time slots** (you may be given a random session if less than **six** time slots were selected).
- In the space provided for names, write the student ID numbers of the four members (for example: "s181514, s201856, s214442, s219088").
- In the space provided for emails, write the email (which will be contacted In case of issues with the schedule) of one group member.

A time slot can be selected by maximum six groups, **do not delay in completing this Doodle**.

In case it is impossible for you to fulfil at least six of the remaining time slots with your group, try to create another group.

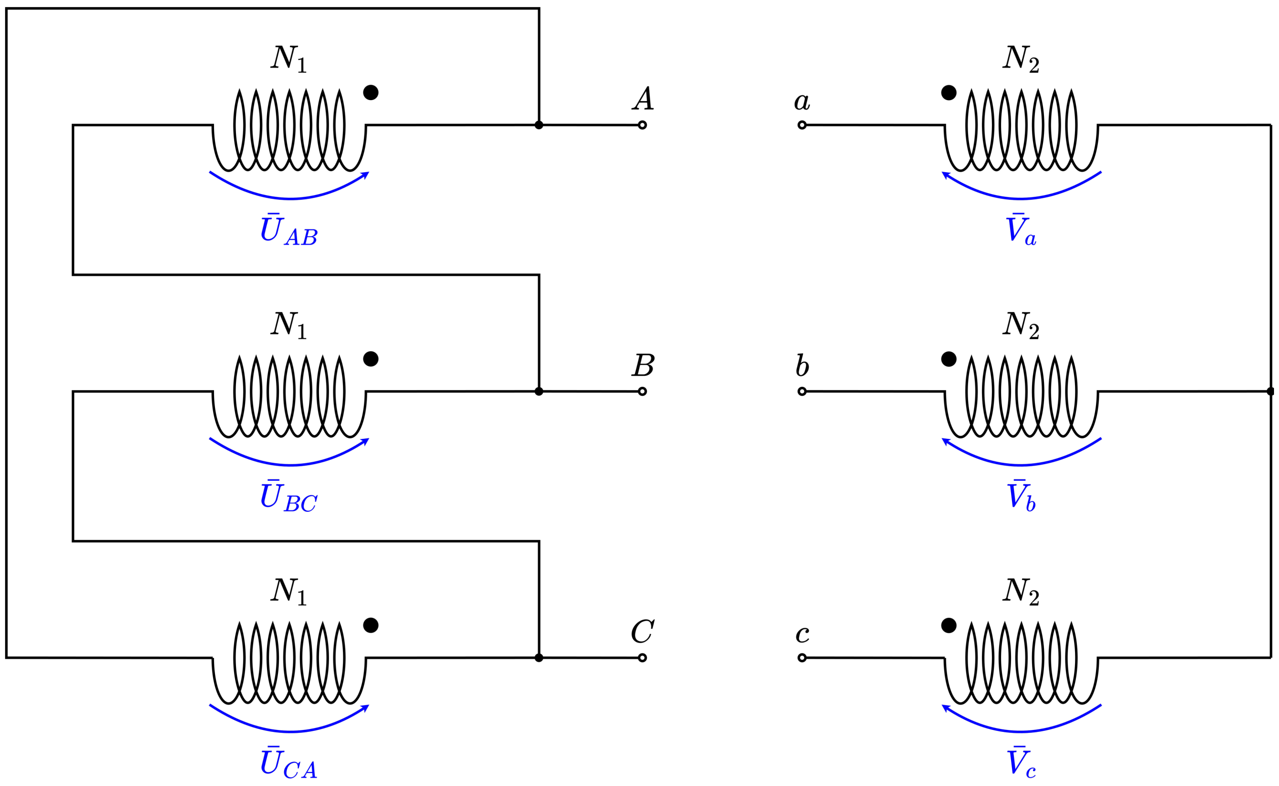
If and only if it is really impossible for you to create a group of four students meeting the requirements, you can fulfil the second doodle "Uncomplete_groups_ELEC0431_lab_schedule" by group of three, two or alone.

- Create a group with a maximum of members.
- Fulfil the doodle **with at least ten available time slots** (you may be given a random session if less than **ten** time slots were selected).
- In the space provided for names, write the student ID numbers of every member (for example: "s181514, s201856, s214442" if you are three).
- In the space provided for emails, write the email (which will be contacted In case of issues with the schedule) of one group member.

Make sure to complete one of these two Doodles by **23:59 on Friday, March 3rd**. Students who would not have given their availabilities by this day will be given random time slots.

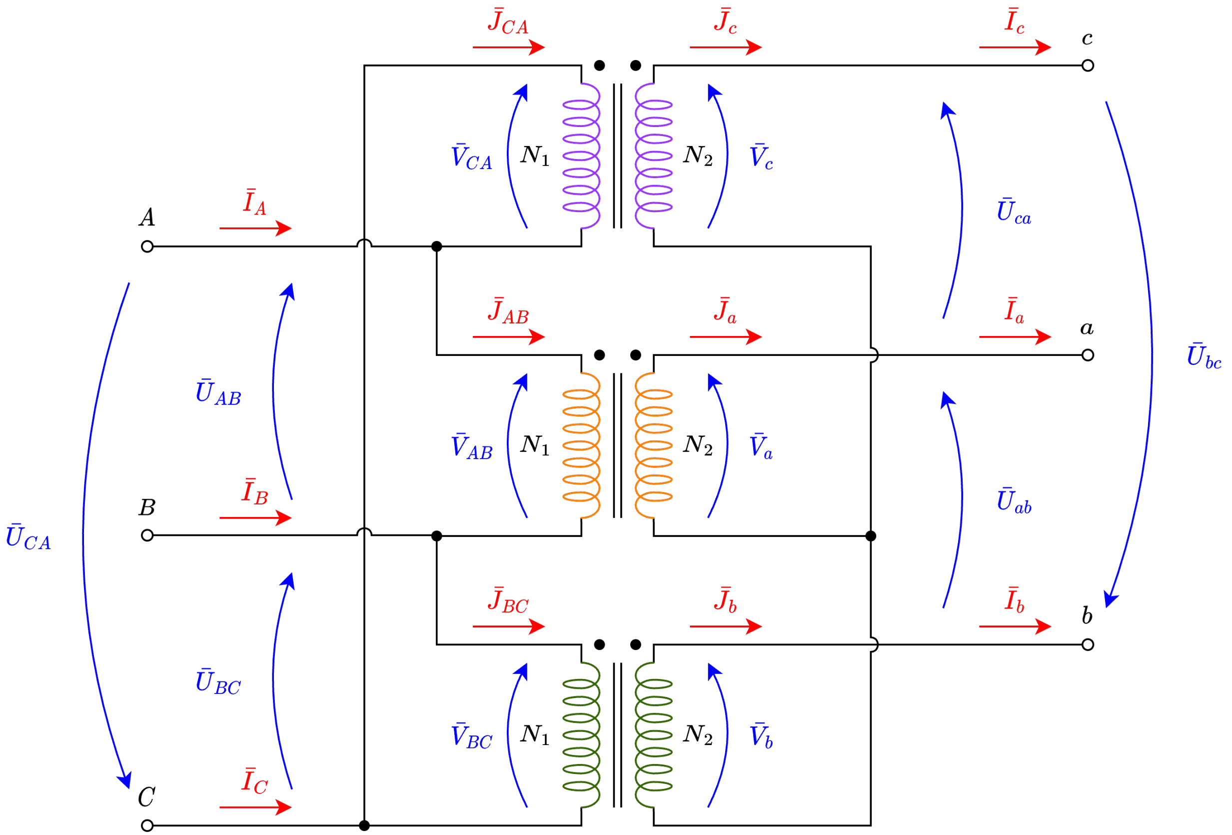
Exercise 9

Three-phase power transformers are commonly used to adapt power line voltages and to provide some galvanic insulation between two parts of an electrical grid. The three-phase transformer, described by the normalized scheme hereunder, is connected to a balanced three-phase network of composed voltages $\overline{U}_{AB}$, $\overline{U}_{BC}$ and $\overline{U}_{CA}$ of RMS voltage U_1 on the primary side, whereas on the secondary side, a three-phase balanced system of composed voltages $\overline{U}_{ab}$, $\overline{U}_{bc}$ and $\overline{U}_{ca}$ of RMS voltage U_2 is obtained. The line current intensities in the primary and secondary windings are respectively denoted I_1 and I_2.



Exercise 9

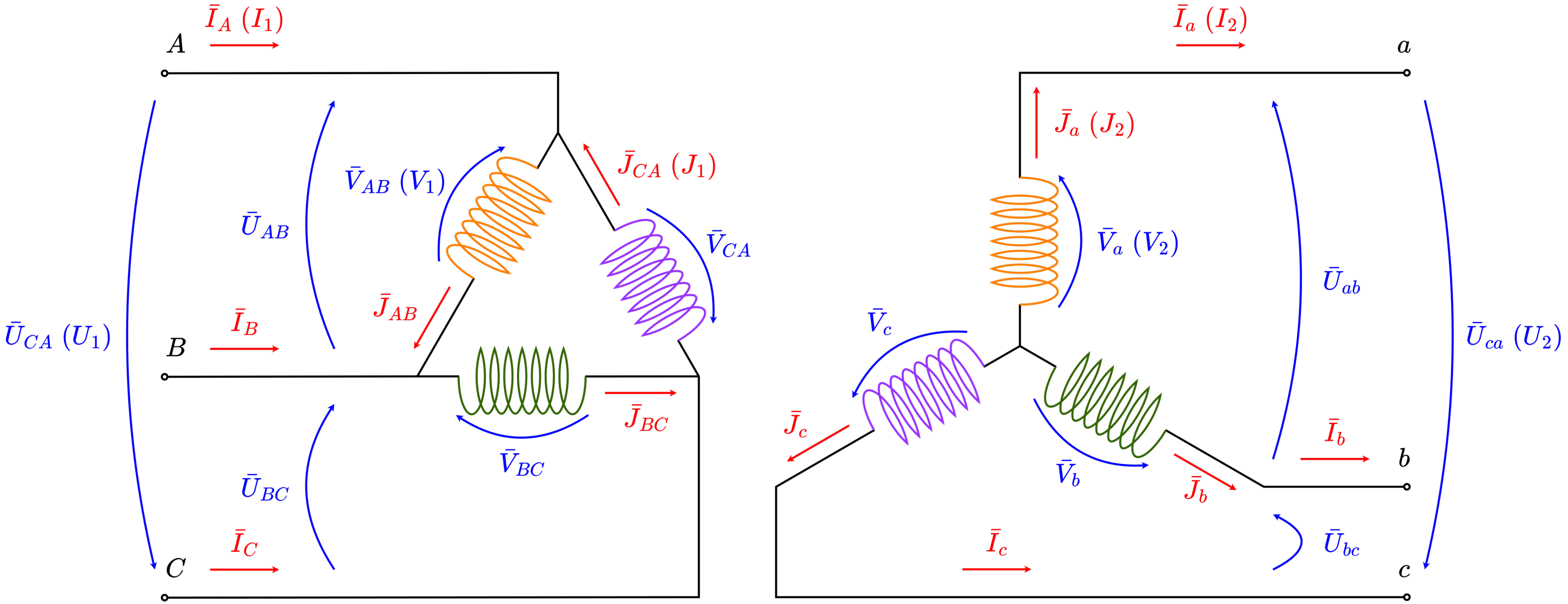
Another way to draw the circuit:



- Each winding at the primary is linked to a winding at the secondary.
- When the system is equilibrated, one can solve it by considering only one phase.
- We define:
  - The column ratio $n_c = \frac{N_2}{N_1} = \frac{V_2}{V_1}$ $\left(\text{or } \frac{N_1}{N_2} = \frac{V_1}{V_2}\right)$
  - The transformer ratio $n = \frac{U_2}{U_1}$ $\left(\text{or } \frac{U_1}{U_2}\right)$

Exercise 9

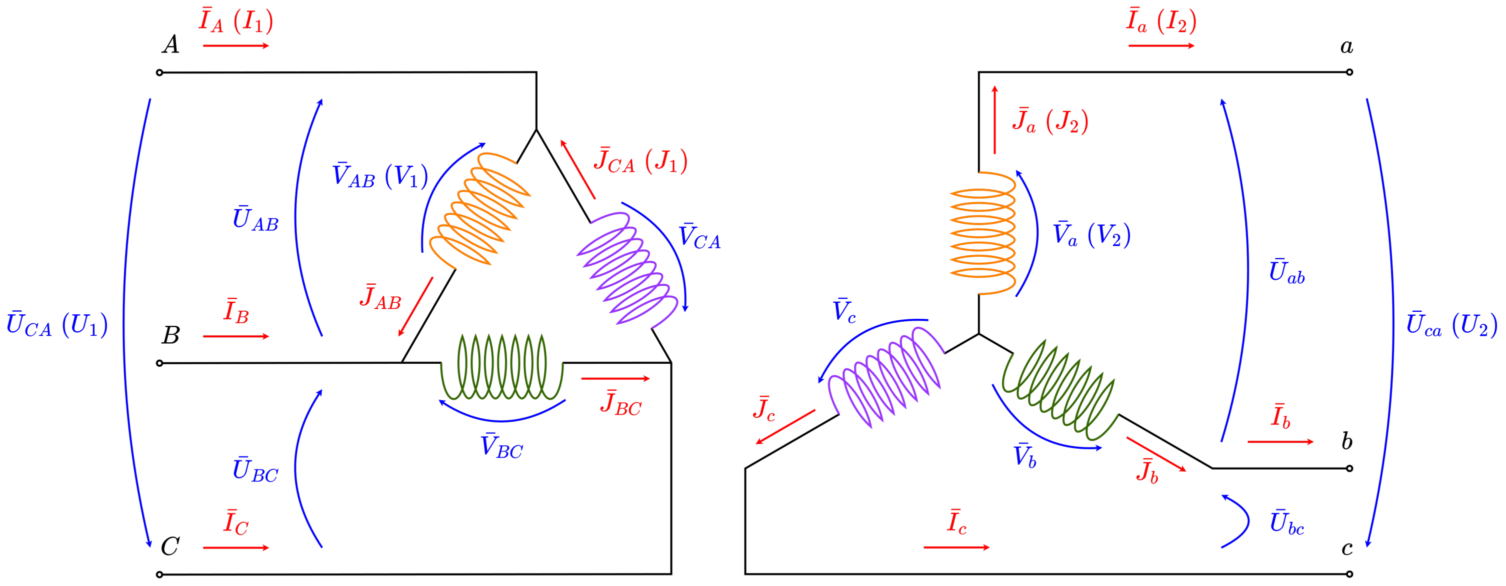
One other way to redraw the circuit:



One can pass from the transformer ratio n to the column ratio n_c by looking at the transformer configuration. Here:

$$n = \frac{U_2}{U_1} = \frac{\sqrt{3}\,V_2}{V_1} = \sqrt{3}\,\frac{n_2}{n_1} = \sqrt{3}\,n_c$$

Exercise 9



The transformer has the following characteristics:

- Apparent nominal power $S_n = 250\ kVA$.
- Composed primary winding RMS voltages $U_{1n} = 5.2\ kV$;
- Nominal frequency $f_n = 50\ Hz$.

And ferromagnetic losses are neglected. To characterize the transformer two tests have been performed:

- Using open secondary windings, the transformer generates a composed voltage of RMS value $U_{2o} = 400\ V$ at each secondary winding, for an applied composed nominal voltage of RMS value U_{1n}.
- Using short-circuited secondary windings, a composed voltage of RMS value $U_1 = 600\ V$ is applied at each primary winding for a total primary power $P = 7.35\ kW$, producing line current of RMS intensity $I_{2s} = 350\ A$.

Exercise 9

1. Calculate the transformer ratio n so that it is greater than 1.

2. For the first test condition (open secondary windings), draw a Fresnel diagram including the primary composed voltages $\overline{U}_{AB}$, $\overline{U}_{BC}$ and $\overline{U}_{CA}$, the direct secondary voltage $\overline{V}_a$, $\overline{V}_b$ and $\overline{V}_c$ and the secondary composed voltages $\overline{U}_{ab}$, $\overline{U}_{bc}$ and $\overline{U}_{ca}$.

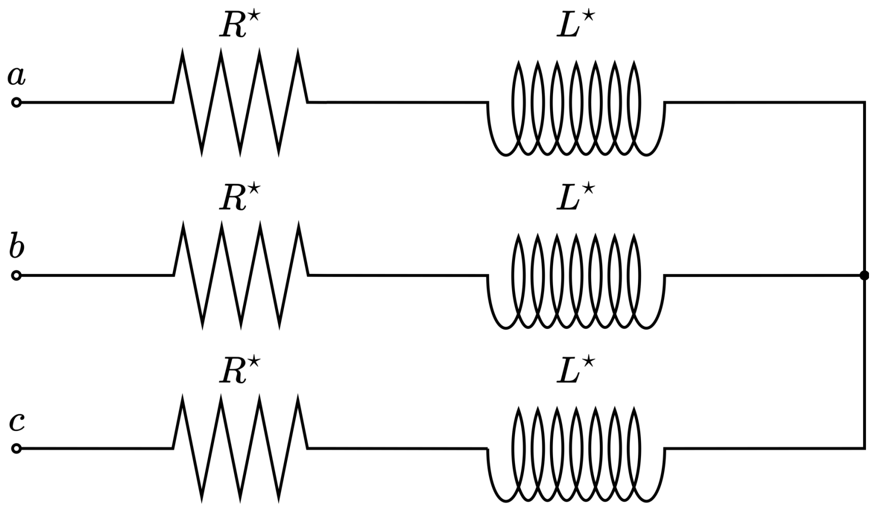
3. Express and compute the column ratio $n_c = \frac{N_1}{N_2}$ according to n.

4. Given that the transformer is composed of 3 cores of section $A_c = 5\ dm^2$, and that the magnetic field amplitude is $B_m = 1.2\ T$, compute the number of turns N_1 of each primary winding and deduce the value of the number of turns of each winding N_2.

5. Using a simple single-phase equivalent model (leak resistance and inductance moved to the secondary windings), provide the Thevenin's model seen from a secondary winding and calculate the resistance R' and the reactance X' of this model;

Exercise 9

The nominal regime is now considered by applying the composed nominal voltage U_{1n} at the primary windings and connecting a three-phase balanced load on the secondary side (detailed here on right). Each branch is composed of a resistor of value $R^{\star} = 554\, m\Omega$ in series with a coil of value $L^{\star} = 3.05\, mH$. From now on, the magnetizing branch of the transformer will be neglected for the following calculations.



6. Calculate the power factor $\cos(\varphi_2)$ of this load.

7. Draw the Fresnel diagram corresponding to the balanced single-phase equivalent model. Deduce the RMS values of the current intensities I_2 and the composed voltages U_2.

8. Compute the active power P_2 flowing from the transformer to the load.

9. Calculate the transformer efficiency η.

Exercise 9

10. Another load is used, compute the value of the resistance R° and the inductance L° such that this load is equivalent to the one detailed in previously.