ELEC0431
Electromagnetic energy conversion

Faculty of Applied Sciences
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Laboratory 1: Transformers

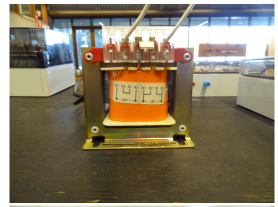
WARNING:

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

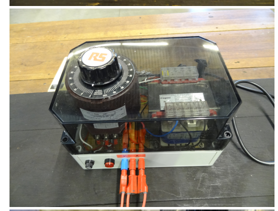
Contents:

1 Single-phase transformer

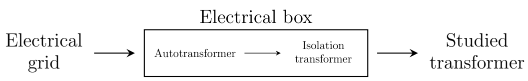
1.1 Components

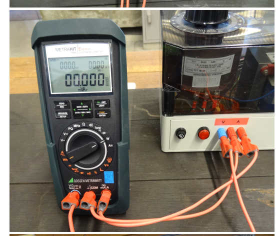


The following single-phase transformer will be studied.



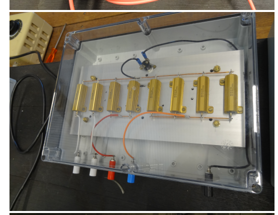
An autotransformer is used to choose its primary voltage and an isolation transformer is added for increased safety. Both of them are placed together in an electrical box.



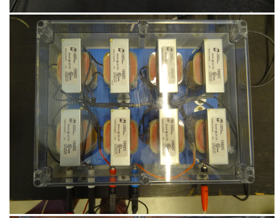


A wattmeter is used to measure the current, voltage and active power at the primary of the studied transformer. To ease the connections, the electrical box has three terminals to connect the wattmeter to ($V \Rightarrow$ voltage, $A \Rightarrow$ current, $C \Rightarrow$ COM).

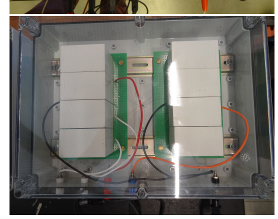
Resistive



Inductive



Capacitive



Three different loads will be connected to the secondary of the studied transformer: a resistive, an inductive and a capacitive load.

To measure the voltage across a load, a voltmeter will be used. Voltmeters are connected in parallel to the load.

To measure the current flowing through a load, an ammeter will be used. Ammeters are connected in series to the load.

Make sure to NEVER connect an ammeter in parallel to a load. It would result in a condition nearly equivalent to a short-circuit, causing a significant current flow that may harm the ammeter.

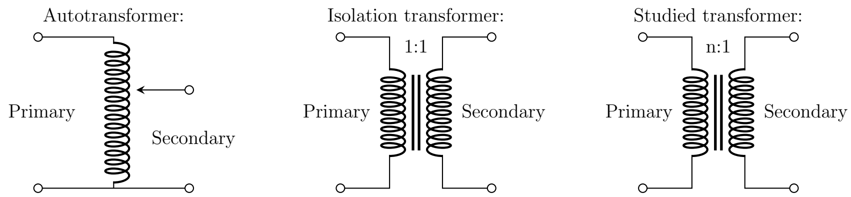
1.2 Start-up

1. Ensure that the rotary switch of the autotransformer is set to "0". In this position, its secondary voltage is null.
2. Connect the plug of the electrical box to the electrical grid.
3. Except for the short-circuit measurement, increase the primary voltage of the studied transformer up to 230 V. **For the short circuit measurements, the voltage should not exceed 10 % of the autotransformer maximum output voltage.**

1.3 Questions

1.3.1 Question 1

Using the hereunder schematics for the auto-, isolation and studied transformers, show how they are connected to each other. Also represent the terminals V, A and C of the electrical box.



1.3.2 Question 2

What is the conversion ratio of the studied transformer, what are its current, voltage and power ratings? **You should not exceed those ratings for the rest of the lab.**

Hint: You will find all the information written on the nameplate on top of the studied transformer.

1.3.3 Question 3

Draw the simplified equivalent model of a single-phase transformer and explain what each of the impedances $R_1, R_2, X_1, X_2, R_{H+F}$ and X_μ stands for.

1.3.4 Question 4

Transformer are usually built so that $R_1, R_2, X_1, X_2 \ll R_{H+F}, X_\mu$. Use this relation to build a second simplified equivalent model of a single-phase transformer, with the impedances gathered and moved to the secondary winding.

1.3.5 Question 5

Considering the simplified equivalent model from Question 4 (impedances gathered and moved to the secondary winding), for which impedances can you determine values through a short-circuit secondary winding measurement?

If the secondary is shorted, what is the maximum current that can run through the primary without exceeding the ratings of the studied transformer?

Perform the short-circuit secondary winding measurement and deduce the appropriate impedance values.

Make sure not to exceed the transformer ratings.

Do not forget to start the test with a null primary voltage.

For this test, the rotary switch of the autotransformer should remain under 10 %.

1.3.6 Question 6

Considering the simplified equivalent model from Question 4 (impedances gathered and moved to the secondary winding), for which impedances can you determine values through an open-circuit secondary winding measurement?

Perform the open-circuit secondary winding measurement and deduce the appropriate impedance values.

Make sure the secondary wires CANNOT touch during the test.

1.3.7 Question 7

In the theoretical class, one makes the hypothesis $X' \gg R'$. Starting from the equivalent model of Question 4 (impedances gathered and moved to the secondary winding) and using this hypothesis, provide an equivalent Thevenin's model of the transfomer, seen from the secondary winding.

Using this Thevenin's equivalent model, draw a phasor diagram that represents the condition of a purely resistive load connected to the secondary coil of the transformer. From it, deduce and draw the theoretical relationship between secondary voltage and secondary current.

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

1.3.8 Question 8

Measure the U-I output characteristic of the studied transformer in case it is connected to the resistive, inductive and capacitive load.
Hint: For each of three loads, vary the load impedance and maintain the primary voltage of the studied transformer to 230 *V by properly turning the rotary switch of the autotransformer. Measure the current flowing through the load using the ammeter (**connected in series to the load**) and the voltage across the load using the voltmeter (connected in parallel to the load).*

Do your measurements match the theoretical curves obtained at Question 7? Why?

1.3.9 Question 9

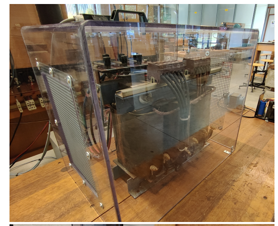
Redo Question 7 by making the opposite hypothesis $R' \gg X'$.

Do the measurements performed at Question 8 match your new development?

2 Tri-phase transformer

2.1 Components

A three-phase transformer will be studied. This transformer stands behind the lab table.

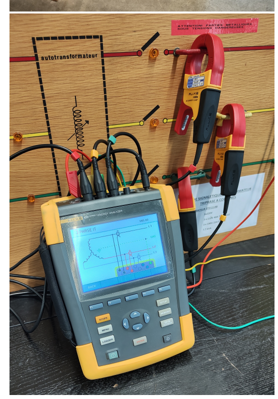


A three-phase autotransformer, whose primary is connected to the three-phase electrical grid, delivers secondary line voltages of adjustable amplitude: turn the rotary switch on top of it to increase or decrease it. The autotransformer secondary is connected to the primary of the studied transformer.

The secondary of the studied transformer is connected to a resistive load, whose value is selected with a rotary switch:

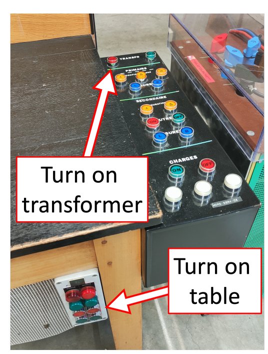
- position 0 $\rightarrow$ open circuit,
- position 1 $\rightarrow$ 27 Ω,
- position 2 $\rightarrow$ $\frac{27}{2}$ Ω,
- position 3 $\rightarrow$ $\frac{27}{3}$ Ω,
- etc.

All the power measurement will be performed using a power quality analyzer (Fluke 434 or equivalent).



2.2 Start-up

1. Ensure that the rotary switch of the autotransformer is set to "0". In this position, its secondary voltage is null.
2. Turn on the table by pressing the red buttons next to the table right leg.
3. Switch on the transformer by pressing the "ON" button on top of the control panel.
4. Except for the short-circuit measurement, increase the primary voltage of the studied transformer up to 120 V. **For the short circuit measurements, the voltage should not exceed 10 % of the autotransformer maximum output voltage.**



2.3 Questions

2.3.1 Question 1

What are the current, voltage and power ratings of the studied transformer? Why are there two current and voltage ratings but only one power rating? **You should not exceed those ratings for the rest of the lab.**

Hint: The ratings are written on the nameplate on top of the studied transformer. It is also rewritten on the table panel.

2.3.2 Question 2

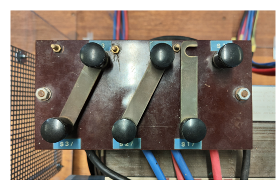
The primary and secondary windings of the studied transformer can be connected in either delta (Δ) or star (Y) configurations. When the transformer is off, you can choose the configuration of either the primary or secondary windings by pressing the relevant button on the control panel to the right of the table.

For each of the four possible combinations (primary and secondary configured as $\Delta\Delta$, YY, ΔY, and YΔ), measure the transformer ratio $n = \frac{U_1}{U_2}$ and link it to the column ratio $n_c = \frac{V_1}{V_2}$. Deduce the value of the column ratio n_c.

2.3.3 Question 3

With the primary and secondary wired in a $\Delta\Delta$ configuration, what is the maximum current that can run through the primary windings without exceeding the ratings of the studied transformer if the secondary windings are shorted?

One can short the secondary windings of the studied transformer by manually connecting the secondary phases together. Note that, when the secondary windings are shorted, the board will stop displaying measurements about the secondary side.
To short or remove the short, ask to a teaching assistant.



Considering the equivalent model of one phase of the studied transformer with impedances gathered and moved to the secondary winding, perform the short-circuit measurement in the $\Delta\Delta$ configuration and deduce the appropriate impedance values assuming the system is balanced.

Do not forget to start the test with a null primary voltage.

Make sure not to exceed the transformer ratings.

For this test, the rotary switch of the autotransformer should remain under 10 %.

2.3.4 Question 4

Considering the equivalent model of one phase of the studied transformer with impedances gathered and moved to the secondary winding, perform the open-circuit measurement in the $\Delta\Delta$ configuration and deduce the appropriate impedance values assuming the system is balanced.

Make sure that the shorts of the secondary windings have been removed.

2.3.5 Question 5

Measure the U-I output characteristic of the studied transformer when it is connected to the resistive load.

Hint: Vary the load impedance and maintain the primary voltage of the studied transformer to 120 *V by properly turning the rotary switch of the autotransformer.*

Do your measurements match the theoretical curve?

2.3.6 Question 6

Place the transformer close to its nominal operating point, in the $\Delta\Delta$ configuration.

Considering the equivalent model of one phase of the studied transformer with impedances gathered and moved to the secondary winding (with the impedance values measured in Question 3 and Question 4), compute the transformer efficiency if only measurements at the primary were available.

Compute now the transformer efficiency by directly taking the secondary to primary active-power ratio. How do you explain the difference with the previously computed value?