Lab-1: AC/DC Circuits and Basic Measurements

Objectives and Overview

The objectives for this sequence of laboratory experiments are:

- to experiment and learn basic properties of single phase RLC circuits, series and parallel connections of components, ideal and non-ideal inductors and capacitors;
- to learn how to measure instantaneous voltages and currents, real, and reactive power; to observe and measure the phase difference between the voltages and currents;
- to learn how to establish phasor representation from the measured currents and voltages for single phase RLC circuits;
- to experiment and learn basic properties of three phase RLC circuits, Wye (star) and Delta connections of components, balanced and unbalanced operation;
- to learn how to measure instantaneous voltages and currents, real, and reactive power in three phase systems; to observe and measure the phase difference between the voltages and currents;
- to learn how to establish phasor representation from the measured currents and voltages for three phase RLC circuits;
- to learn about harmonics in AC mains, basic measurements and evaluations;
- to experiment and learn about single-phase AC-DC rectifier operation, to measure voltages, currents, voltage and current ripple, and power;
- to experiment and learn about three-phase AC-DC rectifier operation, to measure voltages, currents, voltage and current ripple, and power;

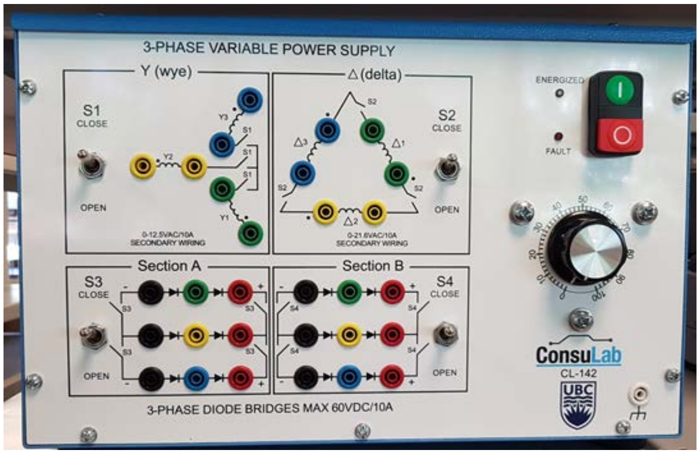
Preparation (Pre-Lab)

It is expected that the students **have read and understood** the textbook chapter and reviewed the lecture notes module corresponding to **AC/DC Circuits, Single Phase and Three Phase Measurements, Real and Reactive Power, and Phasors**. In particular, the students should:

- Review and prepare a list of equations for calculating the series and parallel resistance, inductance, and capacitance in single-phase AC circuit using the measured voltage, current, real power, and the power factor angle.
- Prepare a list of equations for calculating the instantaneous power, real power, and reactive power from the measured instantaneous voltages and currents (single phase and three phase).
- Practice drawing phasors diagrams for the currents and voltages for the Wye and Delta loads as we did in class.
- Make sure that you have access to Matlab and Simulink (and SimscapeElectrical toolbox)

Apparatus & Equipment

This lab includes the following components:

	**3-Phase AC Power Supply:** This flexible 3-phase AC/DC Power Supply has two 3-phase transformers inside, one that can readily be configured into a 'Y' (wye) connection and the other that can be configured into "Δ" (delta). The front panel shows the transformer wiring and has several switches and connectors for configuring the output. It also has two 3-phase diode bridges for producing the DC output. The Power Supply transformers are fed from an internal 3-phase **Variac** (variable auto transformer) that can be used to adjust the output voltage to the desired level. The Variac knob is located on the right of the front panel. By varying the Variac knob from 0 to 100%, the output AC voltages may be changed in the range from 0 to about 25 V (rms) per phase.
	**RL Load Box:** This box contains three 20 Ohms resistors and three 40 mH inductors. These elements could be connected in a variety of ways to implement either single-phase or three-phase RL load.
	**RC Load Box:** This box contains three 60 Ohms resistors and three 40 μF capacitors. These elements could be connected in a variety of ways to implement either single-phase or three-phase RC load.

Measurement Box:

Each bench is equipped with a multi-functional **Measurement Box** that can measure up to 3 voltages and up to 3 currents simultaneously with the sampling rate of 2.5 MS/sec (2.5MHz). The measured waveforms and their values can be displayed on the PC screen as well as recorded for possible post-processing. Its front panel has 3 current channels (**A1, A2, and A3**) and 3 voltage channels (**V1, V2, and V3**), respectively. The current channels are rated to measure and withstand a continuous current of up to 20 A (peak). The voltage channels are rated to measure and withstand the voltage of up to 50 V (peak). For special measurements only, the voltage measurement in each channel can be re-scaled by a factor of 10, thus raising the measurement limit to 500 V (peak). The **Measurement Box** is connected to the Data Acquisition (DAQ) card inside the PC. The **Measurement Box** has one power switch on its back panel on the right side. The power switch should be normally turned ON, and the three LEDs on the front panel should also be ON indicating its normal operation.

The channels are color-coded. It is strongly recommended that you use appropriate and consistent color wires for each channel of measurements. This will make it easier for you to wire-up your circuits and subsequently check it and find any mistakes.

Load Resistor Box: The Load Box contains several resistors from 100 to 50 Ohms, which can be switched on in parallel to each other. The box is equipped with a cooling fan to help dissipate the heat in case there is a significant power delivered to the load. Be careful! This box may get very hot, especially its heat-sink that is on the bottom. **When the box dissipates more than 50W turn on the internal fan.**

Capacitor Box: This box has three electrolytic capacitors that can be switched in parallel. This box is primarily used as a filter for filtering the DC voltage ripple. Be aware that electrolytic capacitors can not be used in reverse polarity, and always make sure that the red terminal is “+” and black terminal is “-“ or the ground terminal.

Setting-Up the DAQ System

Login to your local PC and locate the program **3-Phase Analysis**. Double-click on the icon and start the program. A window shown in Fig. 1 should appear on your PC screen indicating that you are ready to start taking measurements. The **3-Phase Analysis** program interface is set up to display the three voltages (channels V1, V2, and V3) and three currents (channels A1, A2, and A3), as may be needed for either single or three phase measurements. The measurement window can be triggered using either voltage or current signal of the first measuring channel (Ch1). The point of triggering also defines the relative angle of the measured signals. The user can select or un-select the measurement of voltages and currents in Channel 2 and 3 (Channels V2, V3, A2, and A3), but the first channel (V1 and A1) are always selected. For this lab, select all three voltages and currents to be measured.

All measured signals (voltages and currents) are displayed in two ways: On the left side of the panel, all selected variables are displayed as real-time instantaneous waveforms – just like in an Oscilloscope. On the right side of the panel, the RMS values of the voltages (in Volts) and currents (in Amps), their phase angle (in degrees) with respect to the trigger point, and the real power in each channel (in Watts). The fourth line of measurements displays the average RMS voltage, average RMS current, and total real power passed through the measuring device.

The **Measurement Window Period** (in ms) can be adjusted during the process of taking measurements in order to better capture the desired waveforms and to see the details. The button "**Subtract Zero Sequence**" should be "**OFF**." Remember to push buttons **ZERO** before each test to remove any offset when measuring currents. The program is also equipped with a digital low-pass filter with adjustable cut-off frequency that can be used to filter the high frequency components of the measured voltages and currents. The Filter should be turned "**OFF**" for this lab, and you will be measuring and recording actual (unfiltered) voltage and current waveforms.

The program can **PAUSE** and S**AVE** the measured data in a text file for further analysis in programs such as **Excel** or **MATLAB**. Once the measurement is **PAUSED**, the user can also zoom-in into any fragment of the recorded window by using the slide buttons **ZOOM** and **POSITION** on the bottom of the panel. Pushing the bottom **SAVE** brings the window for saving the data file. The user should name the file and save it into appropriate location/folder for future analysis.

Ask a TA and/or Lab Engineer responsible for the lab if you have any problems locating and/or running this program.

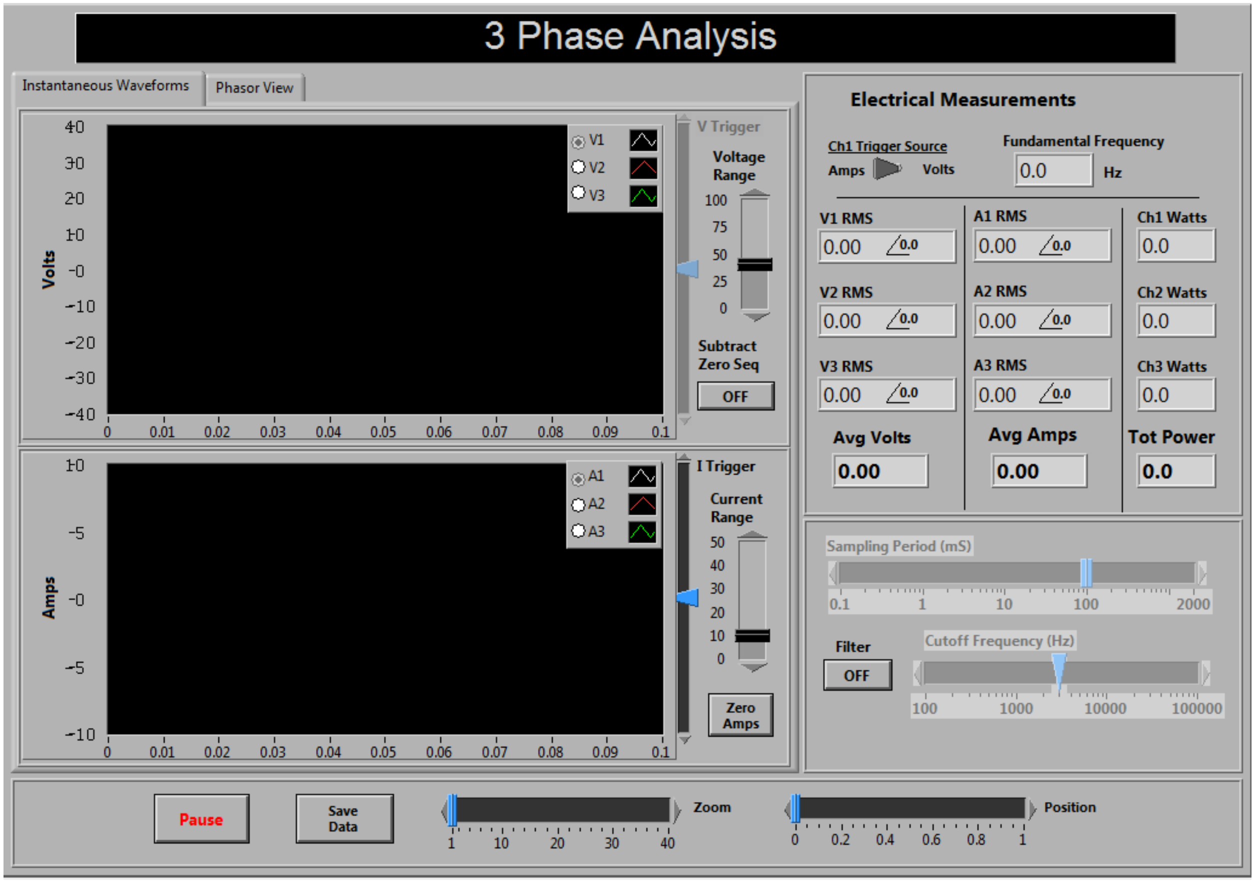


Fig. 1: LabView program interface 3-Phase Analysis.

Experimental Part

Mandatory: As you are performing the experiments and taking measurements, based on your observations and understanding, provide brief answers to the questions listed in your report below each Table of measurements.

Note: In each task, you can verify your calculated phasor diagrams with the <u>Phasor View</u> tab in the LabView program.

Task 1: Single-Phase Measurements with L & C Components

In this Task you will need to use the **3-Phase AC Power Supply** as a source of single phase AC power. You can either use any two terminals of the Y configuration (with the switch S1 closed) or any of the phases of the Delta configuration (switch S2 can be open). You will be using the **RL and RC Load Boxes** to perform a number of basic single phase measurements and calculations. You will use the **Measurement Box** first channel to display the voltage V1 and current A1 in your circuits. Using the wires available on your bench, you will need to subsequently wire several circuits for the following subtasks:

Task 1 A: Measurements with RL Load Box

1) Using the **RL Load Box**, wire the circuit shown in the figure below. First connect only one inductor and the measurement circuit. You will then be using short red wires to connect the other inductors in parallel one at a time.

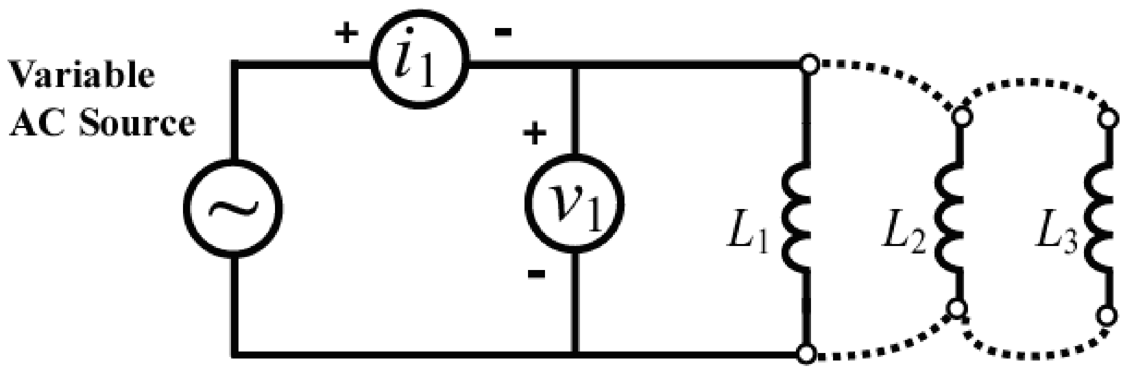


Fig. 2: Single phase parallel inductors wiring diagram.

2) Turn on the **3-Phase AC Power Supply** and slowly increase applied voltage to the level of 17 V. The exact voltage level may be given to you by the TA. The software program **3-Phase Analysis** should display the voltage and current measurements. Adjust the measurement window size so that you can clearly see several complete AC cycles.
3) Record the first set of measurements in the Table 1. Then connect all the inductors in parallel and take another set of measurements. Record all measurements in Table 1.
4) Using the relationships in your **Pre-Lab page**, calculate the resulting equivalent impedance Z, equivalent inductance L, and equivalent series resistance R for all three cases.

Task 1 B: Measurements with RC Load Box

1) Using the **RC Load Box**, wire the circuit shown in the figure below. First connect only one capacitor and the measurement circuit. You will then be using short red wires to connect the other capacitors in parallel one at a time.

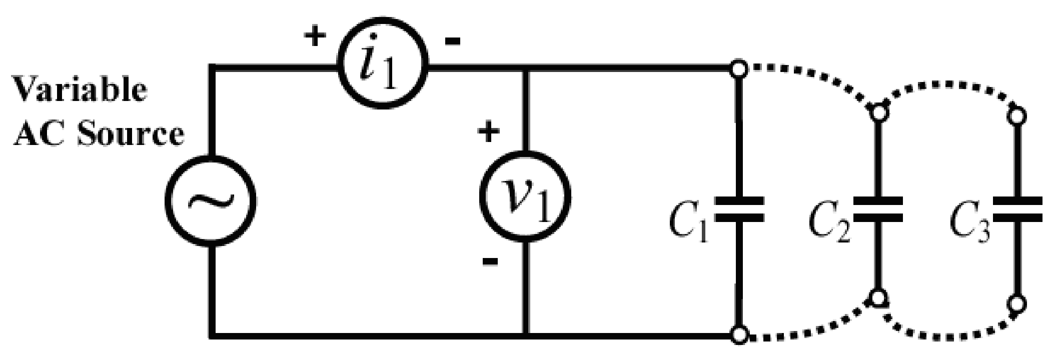


Fig. 3: Single phase parallel capacitors wiring diagram.

2) Turn on the **3-Phase AC Power Supply** and slowly increase applied voltage to the level of 15 to 25 V. The exact voltage level may be given to you by the TA. The software program **3-Phase Analysis** should display the voltage and current measurements. Adjust the measurement window size so that you can clearly see several complete AC cycles.
3) Record the first set of measurements in the Table 2. Then connect all the capacitors in parallel and take another set of measurements. Record all measurements in Table 2.
4) Using the relationships in your **Pre-Lab page**, calculate the resulting equivalent impedance Z, equivalent capacitance C, and equivalent parallel resistance R for all three cases.

Task 1 C: Parallel connection of RLC components

1) Using both the **RL Load Box** and **RC Load Box,** wire the circuit shown in the figure below. First connect only one 20 Ohm resistor from the **RL Load Box** and the measurement circuit for the Channel 1 to measure V1 and A1. You will then be using short red wires to connect one inductor and all the capacitors in parallel.

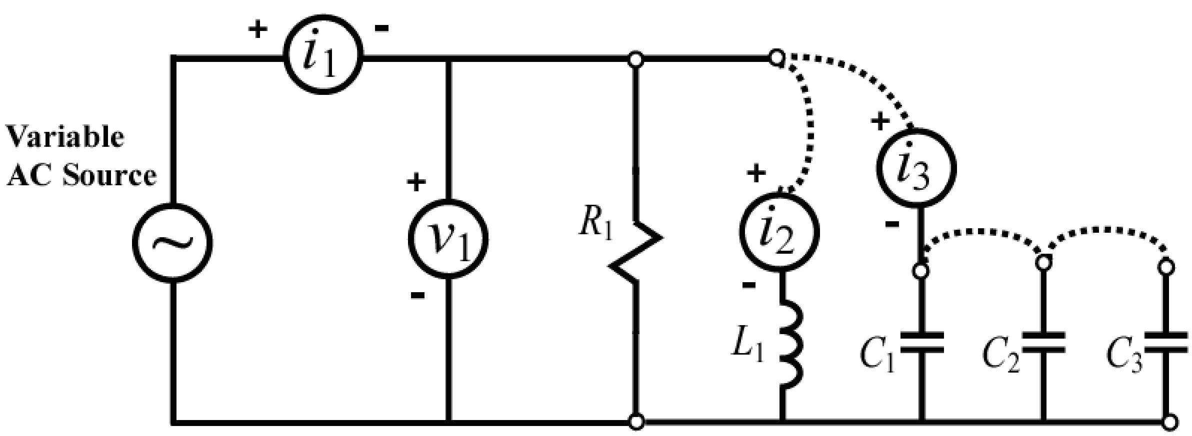


Fig. 4: Wiring diagram of parallel connection of RLC components.

2) Turn on the **3-Phase AC Power Supply** and slowly increase applied voltage to the level of 15 to 25 V. The exact voltage level may be given to you by the TA. The software program **3-Phase Analysis** should display the voltage and current measurements.
3) The first measurement should correspond to just one resistor from **RL Load Box** being supplied from the AC source. Adjust the measurement window size so that you can clearly see several complete AC cycles. Record the first set of measurements in the Table 3. Also, **PAUSE** and **SAVE** these measured waveforms. You will then use these recorded waveforms for calculating the instantaneous power, real power, and reactive power, and for plotting the results in your Lab report.
4) Then connect the inductor in parallel to the resistor. Record the second set of measurements in the Table 3. Also, **PAUSE** and **SAVE** these measured waveforms for future calculations.
5) Leave the inductor connected. Then connect all the three capacitors in parallel to the inductor (capacitors should be in parallel themselves), and record the measurements in Table 3. Also **PAUSE** and **SAVE** these measured waveforms for future calculations.

Task 1 D: Series connection of RLC components

1) Using both the **RL Load Box** and the **RC Load Box**, wire the circuit shown in the figure below. First connect only one resistor and one inductor from the **RL Load Box**, as well as only one capacitor from the **RC Load Box**. Use V1 and A1 to measure the source voltage and current**.** Also connect the voltmeter channels V2 and V3 to measure the voltage across the inductor and capacitor, respectively.

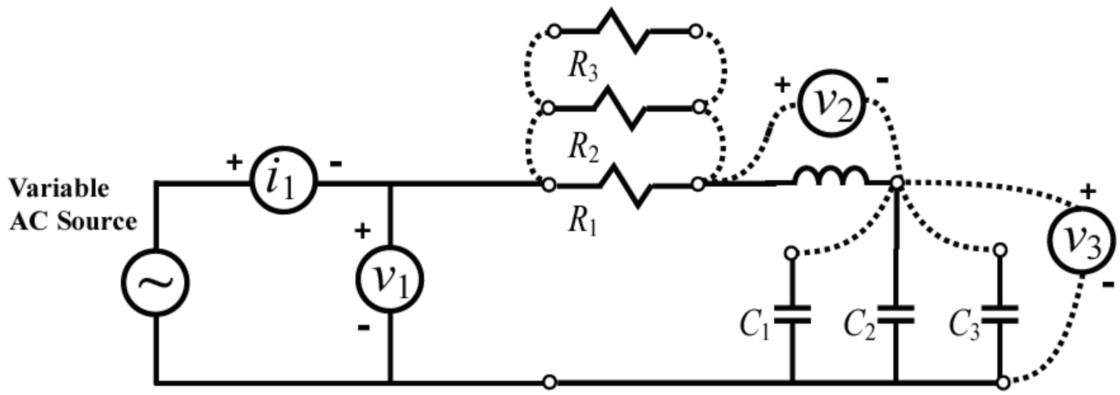


Fig. 5: Wiring diagram of series connection of RLC components.

2) Turn on the **3-Phase AC Power Supply** and slowly increase applied voltage to the level of 15 V. The exact voltage level may be given to you by the TA. The software program **3-Phase Analysis** should display the voltage and current measurements. Adjust the measurement window size so that you can clearly see several complete AC cycles.
3) The first measurement should correspond to just one resistor one inductor from **RL Load Box** and one capacitor from **RC Load Box** all connected in series and supplied from the AC source. Record the first set of measurements in Table 4. (the corresponding row should be added)
4) The next measurement is with all three capacitors connected in parallel. Also record this in Table 4 and **SAVE** these measured waveforms for future calculations.
5) Leave all capacitors connected, and connect the three resistors in parallel. Record this set of measurements in the Table 4. Also **SAVE** the measured waveforms for future calculations.

You will then use the recorded waveforms for calculating the instantaneous power, real power, and reactive power, and for plotting the results in your Lab report.

Task 2: Three-Phase Measurements with RLC Components

In this Task you will need to use the **3-Phase AC Power Supply** as a source of three phase AC power. You will use the Y configuration (with the switch S1 closed) so that the neutral point can be accessed. You will be using the **RL and RC Load Boxes** to perform a number of basic three phase measurements and calculations. You will use the **Measurement Box** all three channels to display the voltages V1, V2, V3, and currents A1, A2, A3, in your circuits. Pay particular attention to the polarity of the voltage and current measuring channels. Using the wires available on your bench, you will need to subsequently wire several circuits for the following subtasks:

Task 2 A: Three-Phase Measurements with Y-connected RL Load Box

1) Using the **RL Load Box,** wire the circuit shown in the figure below. First connect only the current measurement circuit and the Wye-connected RL load. You will then be using short red wires to bypass (short-circuit) elements in one of the phases, as well as to connect the neutral points of the source and the load.

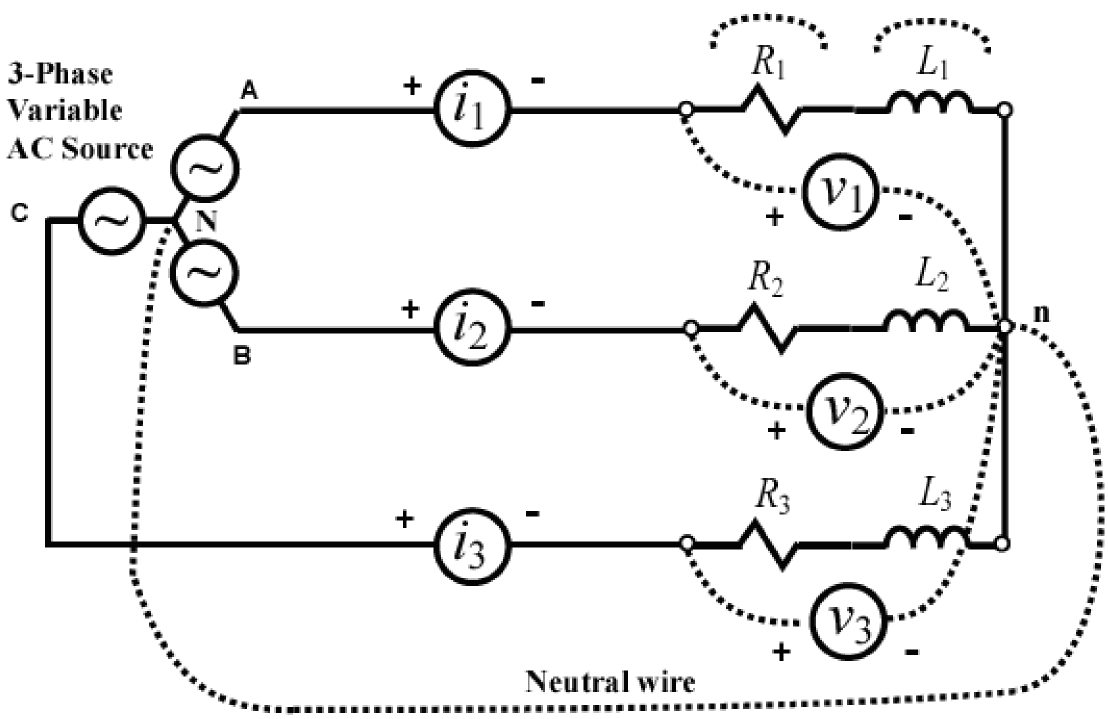


Fig. 6: Three phase Y-connected RL load wiring diagram.

2) Turn on the **3-Phase AC Power Supply** and slowly increase applied **phase voltage** to the level of 10 V. The exact voltage level may be given to you by the TA. The software program **3-Phase Analysis** should display the voltage and current measurements. Adjust the measurement window size so that you can clearly see several complete AC cycles.
3) Record the first set of measurements in the Table 5. Write down the RMS value and the angle of each voltage and current. Also record the measured waveforms for future calculations using **PAUSE** and **SAVE** buttons.
4) Then short-circuit one resistor in one of the phases, and record the RMS value and angle of each voltage and current in Table 5. Remove the short, and now repeat the same test with the shorted inductor in the same phase. Again record the measurements in Table 5. Also record the measured waveforms for future calculations using **PAUSE** and **SAVE** buttons.
5) Connect the Neutral Wire between the source and the load. Repeat the step 4) and record the measured waveforms of the last measurement with the shorted inductor for future calculations using **PAUSE** and **SAVE** buttons.

Task 2 B: Three-Phase Measurements with Delta-connected RL Load Box

1) Using the **RL Load Box** wire the circuit shown in the figure below. First connect only the current measurement circuit and the Delta-connected RL load. Then connect the voltmeter channels, which will form a floating neutral point. You will then be using short red wires to bypass (short-circuit) elements in one of the phases.

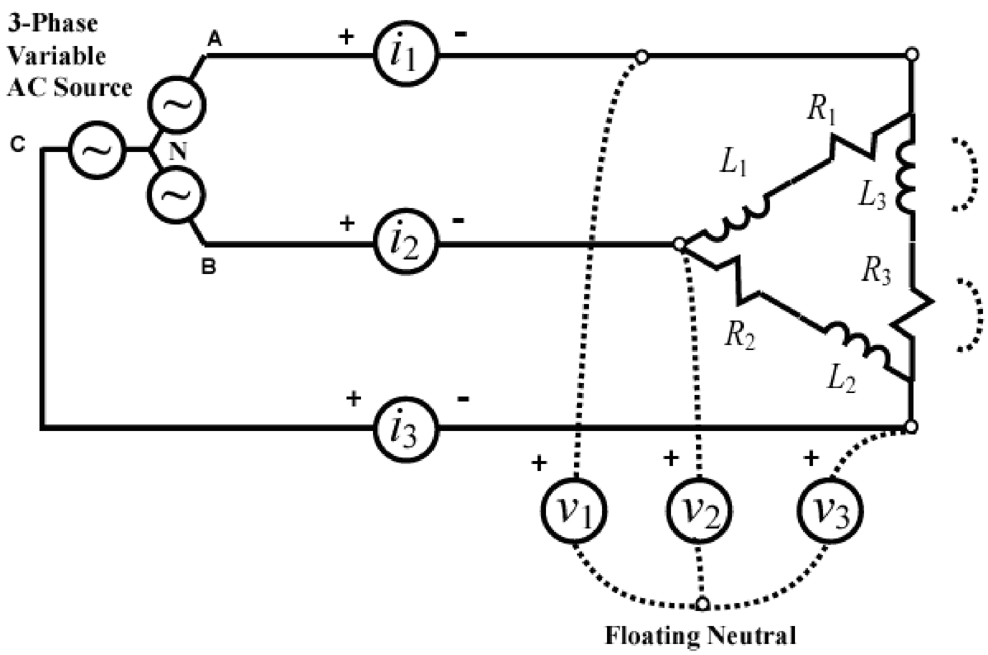


Fig. 7: Three phase Delta-connected RL load wiring diagram.

2) Turn on the **3-Phase AC Power Supply** and slowly increase applied **phase voltage** to the level of 10 V. The exact voltage level may be given to you by the TA. The software program **3-Phase Analysis** should display the voltage and current measurements. Adjust the measurement window size so that you can clearly see several complete AC cycles.
3) Record the first set of measurements in the Table 6. Write down the RMS value and the angle of each voltage and current.
4) Then short-circuit one resistor in one of the phases, and record the RMS value and angle of each voltage and current in Table 6. Remove the short, and now repeat the same test with the shorted inductor in the same phase. Again record the measurements in Table 6.

Task 2 C: Two Wattmeter Measurement Method with Delta-connected RL Load Box (Canceled for Virtual/Online Mode)

1) Using the **RL Load Box** wire the circuit shown in the figure below. This can be easily achieved by removing the current channel A3 and voltage channel V3. This method of measurements is sometimes referred to as the **Two Wattmeter Method**. You will need to verify if the real power measured in this task matches the measurements in the previous task for the same Delta-connected load. First connect only the current measurement circuit and the Delta-connected RL load, and then the remaining two voltmeter channels. You will then be using short red wires to bypass (short-circuit) elements in one of the phases.

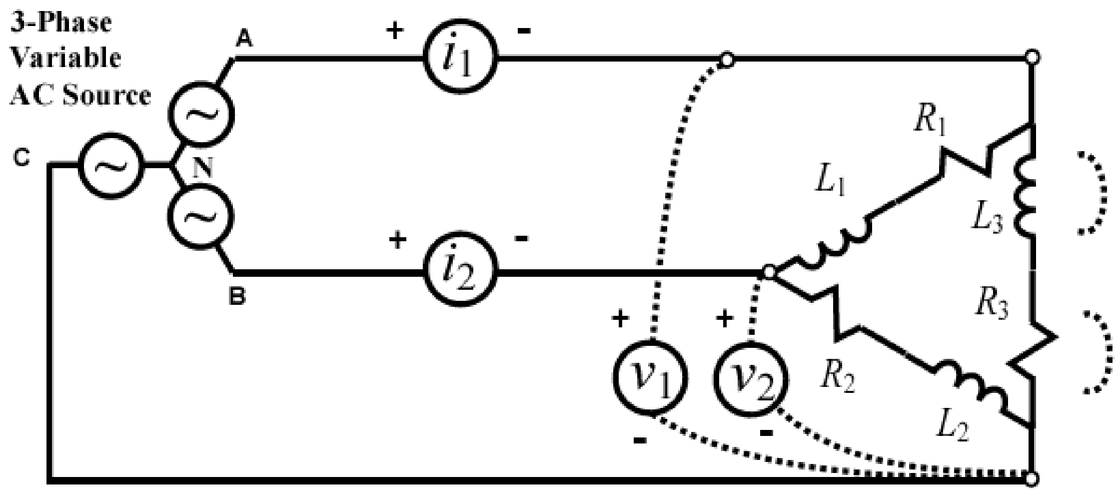


Fig. 8: Three phase delta-connected RL load with two-wattmeter method.

2) Turn on the **3-Phase AC Power Supply** and slowly increase applied voltage to the level of 17.3 V. The exact voltage level may be given to you by the TA. The software program **3-Phase Analysis** should display the voltage and current measurements. Adjust the measurement window size so that you can clearly see several complete AC cycles.
3) Record the first set of measurements in the Table 7. Write down the RMS value and the angle of each voltage and current.
4) Then short-circuit one resistor in one of the phases, and record the RMS value and angle of each voltage and current in Table 7. Then remove the short, and now repeat the same test with the shorted inductor in the same phase. Again record the measurements in Table 7.

Task 3: Single-Phase AC-DC Diode Rectifiers

In this Task you will need to use the **3-Phase AC Power Supply** as a source of single phase AC power. You will use the diodes on the front panel of the power supply to configure the full-wave rectifier. You will be using the **Load Resistor Box** to implement a variable load and the **Capacitor Box** for filtering the voltage ripple. You will use the **Measurement Box** all three channels to display the voltages V1, V2, V3, and currents A1, A2, A3, in your circuits. Using the wires available on your bench, you will need to subsequently wire several circuits for the following subtasks:

Task 3 A: Single Phase Full-Wave Rectifier (without and with capacitor filter)

1) Wire-up the circuit shown in the figure below. First connect the current measurement circuit A1, A3, four diodes to form a bridge, **Capacitor Box**, and the **Load Box**. Then connect the voltmeter channels V1 and V3.

Note: The red terminal of capacitor box should be connected to positive polarity and the black terminal should be connected to negative polarity.

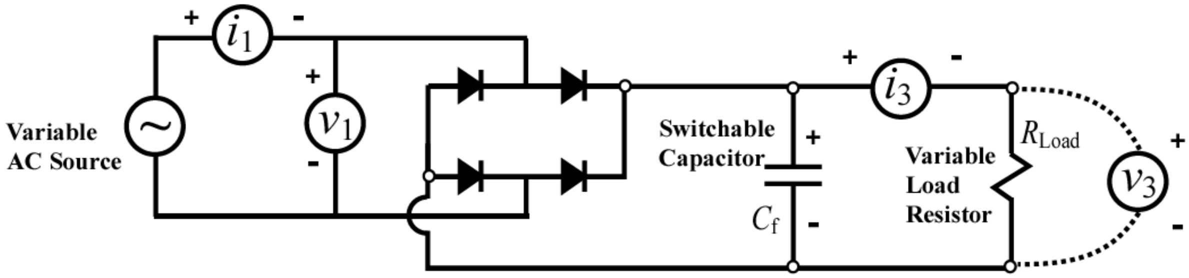


Fig. 9: Single phase full-wave rectifier wiring diagram.

2) Turn on the **3-Phase AC Power Supply** and slowly increase applied voltage to the level of 12 V. The exact voltage level may be given to you by the TA. The software program **3-Phase Analysis** should display the voltage and current measurements. Adjust the measurement window size so that you can clearly see several complete AC cycles.
3) We will now test the circuit **without** the capacitor filter. Initially, all capacitors in the **Capacitor Box** and all the resistors in the **Load Box** should be switched OFF (no load condition). You will then switch ON half of the resistors in the **Load Box** (light load condition). Finally, switch ON all the resistor in the **Load Box** (heavy load condition). Each time record the measurements in Table 8A. Based on the observed waveforms, estimate (measure) the ripple and/or peak of the currents and voltages and record the respective values in Table 8A. The input current should now be in both positive and negative direction due to the full-wave rectification.
4) We will now test the circuit **with** the capacitor filter. Initially, all the resistors in the **Load Box** should be switched OFF (no load condition). Now switch ON all capacitors in the **Capacitor Box** to filter (smooth) the output voltage so that it looks more like DC. You will then switch ON half of the resistors in the **Load Box** (light load condition). Finally, switch ON all the resistor in the **Load Box** (heavy load condition). Each time record the measurements in Table 8B. Based on the observed waveforms, estimate (measure) the ripple and/or peak of the currents and voltages and record the respective values in Table 8B. You should see that the output voltage and current become much smoother due to the capacitor filtering. However, this will also make the input current to have a very significant spike/peak. The value of this spike may be significantly higher than the output DC current. Also record the measured waveforms for the last measurement with all load resistors connected for future calculations using **PAUSE** and **SAVE** buttons.

Task 4: Three-Phase Full-Wave AC-DC Diode Rectifiers

1) Wire-up the circuit shown in the figure below. First connect the current measurement circuit A1, A2, A3, six diodes to form a 3-phase bridge, **Capacitor Box**, and the **Load Box**. Then connect the voltmeter channels V1, V2 and V3.

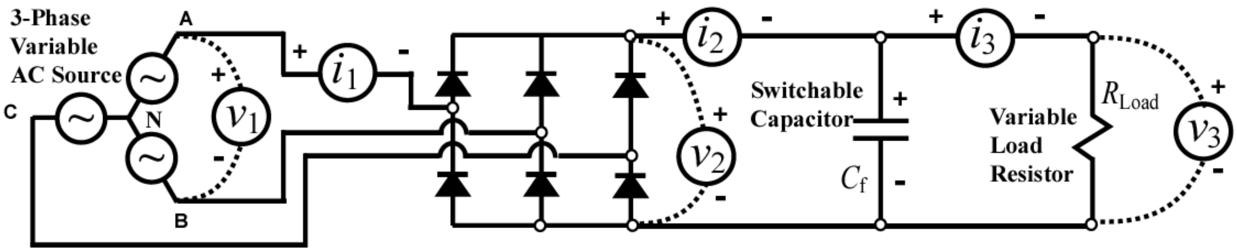


Fig. 10: Three-phase full-wave rectifier wiring diagram.

2) Turn on the **3-Phase AC Power Supply** and slowly increase applied voltage to the level of 10 V. The exact voltage level may be given to you by the TA. The software program **3-Phase Analysis** should display the voltage and current measurements. Adjust the measurement window size so that you can clearly see several complete AC cycles.
3) We will now test the circuit **without** the capacitor filter. Initially, all capacitors in the **Capacitor Box** and all the resistors in the **Load Box** should be switched OFF (no load condition). You will then switch ON half of the resistors in the **Load Box** (light load condition). Finally, switch ON all the resistor in the **Load Box** (heavy load condition). Each time record the measurements in Table 9A. Based on the observed waveforms, estimate (measure) the ripple and/or peak of the currents and voltages and record the respective values in Table 9A. You should see that the output DC current and voltage are better – have smaller ripple than it was in the case of single phase rectifier.
4) We will now test the circuit **with** the capacitor filter. Initially, all the resistors in the **Load Box** should be switched OFF (no load condition). Now switch ON all capacitors in the **Capacitor Box** to filter the output voltage so that it looks more like DC. You will then switch ON half of the resistors in the **Load Box** (light load condition). Finally, switch ON all the resistor in the **Load Box** (heavy load condition). Each time record the measurements in Table 9B. Based on the observed waveforms, estimate (measure) the ripple and/or peak of the currents and voltages and record the respective values in Table 9B. You should see that the output voltage and current become much smoother due to the capacitor filtering. However, this will also cause the input current to have a very significant spikes/peaks. The value of this spike may be significantly higher than the output DC current! Also, using **PAUSE** and **SAVE** buttons, record the measured waveforms for the last measurement with all load resistors connected for future calculations and comparisons with simulations using Simulink (Simscape Electrical toolbox).

Task 5: Calculations and Analysis

This part must be included with your Lab Report. You are very strongly encouraged to use **MATLAB** or Excel (or an equivalent powerful tool) for performing the calculations, plotting the recorded and calculated waveforms, and plotting the phasors diagrams. Properly label all the plot axes including the units on all plots and phasors diagrams.

Task 5 A: Instantaneous, Real, and Reactive Power in Parallel RCL Circuit

Calculate the instantaneous, real, and reactive power based on the recorded data from the Task 1C, Step 3. Plot your results on separate subplots such that you can clearly see all calculated powers one after another. You can do it in **Matlab**, or you can import the measured data into **Simulink**, and read it from there into your Simulink model where you set up your calculations.

Repeat similar calculations for the data recorded in Task 1C, Steps 4 and 5, and plot the instantaneous, real, and reactive power. Based on your results, briefly explain the meaning of instantaneous, real, and reactive power. How has adding an inductor and capacitors in your case changed the reactive and real power that you have measured in this Task?

Based on the measurement in Task 1C, Step 5, draw (using program, e.g. MATLAB or Excel, not by hand!) the phasor diagram for this case showing the applied voltage V1, the input current I1, the inductor current I2 and the capacitor current I3.

Task 5 B: Single-Phase Phasor Diagram for the Series RLC Circuit

Based on the measurement in Task 1D, Step 4, draw (using MATLAB or Excel, not by hand!) the phasor diagram for this case showing the applied voltage V1, the input current I1, the inductor voltage V2 and the capacitor voltage V3. Then, repeat the same for the measurement of Step 5. Based on your diagrams, how does the voltages across the inductor and capacitor relate to the applied voltage?

Task 5 C: Three-Phase Phasor Diagrams for Wye-connected RL Load

Based on the measurement in Task 2A, Step 3, draw (using MATLAB or Excel, not by hand!) the phasor diagram for this case showing the applied phase voltages V1, V2, V3, and input currents I1, I2, I3. Then, repeat the same for the measurement of Step 4 and Step 5.

Based on your diagrams, how does the unbalanced load affect the phase voltages when the neutral point on the load is not connected to the source neutral? What is the effect of connecting the neutral points in Step 5?

What would happen in case of unbalanced load if the load phases are connected in Delta as in Task 2B? Explain based on your measurements in the Table 6.

Task 5 D: Harmonics in AC mains

Using any of the measured/recorded voltages in Task 1 or 2, first plot the recorded voltage waveform. How close is this waveform to an ideal sinusoid? Use MATLAB FFT command (or an equivalent tool) to calculate the harmonic content. Also plot this result such that the harmonic amplitudes are either in volts or normalized with respect to the fundamental component. The frequency axis should have units of Hz. You can read help on FFT on the MATLAB command line and/or read online documentation to learn how this function should be properly used. You will need to rescale the output of the FFT to display the harmonic spectrum properly!

What do you think can cause harmonics in AC systems and in the Lab in particular?

Task 5 E: Single-Phase AC-DC Rectifiers

Using the measured/recorded current from Task 3A, first plot the recorded current waveform. How close is this waveform to an ideal sinusoid? Use MATLAB FFT command (or an equivalent tool) to calculate the harmonic content. Also plot this content where the harmonic amplitudes are either in Amps or normalized with respect to the fundamental component, same as you did in Task 5D.

What could be the result of such loads on the AC Mains?

Task 5 F: Three-Phase AC-DC Rectifiers

Using the measured/recorded currents from Task 4, Step 4, plot the recorded currents I1, I2, I3 waveforms. Explain the difference between I2 and I3.

Use MATLAB FFT command to calculate the harmonic content of the phase current I1. How does the waveform of the phase current I1 in Task 4 is different from current I1 in Task 3A?

Optional: Try to use Simulink toolbox **Simscape Electrical**, and reproduce the system of Fig. 10, and study Task 4, Step 4. Plot and compare the peaks of AC currents and values of DC currents in your simulation vs. lab measurements under the full DC load. Comment on similarity and differences.

Reporting

Prepare the Lab Report that includes:

1) Title Page (all filled-in, with electronic signatures).

2) Pre-Lab (scanned or pictures of pages).

3) Pages 17 to 24 with measured data. The tables of measurements are included in the manual for most of the experiments. These pages with tables must contain your own measurements/calculations. Some Tasks include observation questions that you should answer directly on these pages.

4) For each task, include necessary diagrams, tables of measurements, figures, graphs, equations, calculations, notes, etc.

5) **Calculations & Analysis:** include appropriate equations, calculations, comments and observations as per Task 5.

6) **Summary Section:** Briefly state and summarize what you have learned doing the experiments and subsequent calculations.

7) **Appendix:** Please include any Matlab code or windows of Simulink models that you have used for this lab.

Note: All reports must be typed. No exception.

Submit your report in electronic form <u>as a single PDF file</u> to Canvas system for this course before the stated deadline.

ELEC 342

Lab Experiment: ___

Section: ___

Bench #: ___

Partners	Student ID	% participation	Signatures

Date Performed:

Date Submitted:

Task 1 A: Measurements with RL Load Box

Table 1: Single phase parallel inductors

Measurement	$V_1(rms), V$	$I_1(rms), A$	$\varphi_1 = \theta_V - \theta_I$	$P_1(ave), W$	Z_{eq}, Ω	R_{eq_series}, Ω	L_{eq}, H
one inductor							
three inductors							

- How is this inductor different from an ideal inductor element?
- Are the calculated values of inductance close to the expected value? What is the difference?

Task 1 B: Measurements with RC Load Box

Table 2: Single phase parallel capacitors

Measurement	$V_1(rms), V$	$I_1(rms), A$	$\varphi_1 = \theta_V - \theta_I$	$P_1(ave), W$	Z_{eq}, Ω	$R_{eq\_parallel}, \Omega$	C_{eq}, F
one capacitor							
three capacitors							

- How is this capacitor different from an ideal capacitor element?
- Are the calculated values of capacitance close to the expected value? What is the difference?

Task 1 C: Parallel connection of RLC components

Table 3: Parallel connection of RLC components. Supply voltage V1 = $(rms)\angle$

Measurement	$I_1(rms), A$	$\varphi_1 = \theta_{V1} - \theta_{I1}$	$I_2(rms), A$	$\varphi_2 = \theta_{V1} - \theta_{I2}$	$I_3(rms), A$	$\varphi_3 = \theta_{V1} - \theta_{I3}$	$P_1(ave), W$
one resistor R_1							
R_1 and L_1							
$R_1, L_1, C_1 + C_2 + C_3$							

- How has the real power changed when you connected inductors and capacitors in parallel?

- How are the magnitudes of the currents I1, I2, and I3 related to each other when all elements are connected in parallel?

- Can either I2 and/or I3 have magnitude larger than the magnitude of I1? Explain.

Task 1 D: Series connection of RLC components

Table 4: Series connection of RLC components. Supply voltage V1 = $(rms)\angle$

Measurement	$I_1(rms), A$	$\varphi_1 = \theta_{V1} - \theta_{I1}$	$V_2(rms), V$	$\theta_{V1} - \theta_{V2}$	$V_3(rms), V$	$\theta_{V1} - \theta_{V3}$	$P_1(ave), W$
R_1, L_1, C_1							
$R_1, L_1, C_1 + C_2 + C_3$							
$R_1, R_2, R_3, L_1, C_1 + C_2 + C_3$							

- How has the real power changed when you connected capacitors in parallel or resistors in parallel?

- How are the magnitudes of voltages V1, V2, and V3 related to each other when all elements are connected in series?

- Can either V2 and/or V3 have magnitude larger than the magnitude of V1? Explain.

- Support your answer with the phasor diagram corresponding to the measurement Task 1 D, step 5).

Task 2 A: Three-Phase Measurements with Y-connected RL Load Box

Table 5: Balanced and unbalanced Y-connected RL three-phase load.

Measurement	$V_1(rms)\angle\varphi_v$	$I_1(rms)\angle\varphi_i$	$V_2(rms)\angle\varphi_v$	$I_2(rms)\angle\varphi_i$	$V_3(rms)\angle\varphi_v$	$I_3(rms)\angle\varphi_i$	$P_{total}\,(ave),W$
RL balanced load, neutrals disconnected **(save waveforms)**							
RL unbalanced load, shorted resistor, neutrals disconnected							
RL unbalanced load, shorted inductor, neutrals disconnected **(save waveforms)**							
RL unbalanced load, shorted resistor, neutrals connected							
RL unbalanced load, shorted inductor, neutrals connected **(save waveforms)**							

- How close your measurements are to the ideal case when the RL load is balanced?

- What happens to the phase voltages and currents when the resistor is shorted in one of the phases?

- What happens to the phase voltages and currents when the inductor is shorted in one of the phases?

- How does connecting or disconnecting the Neutral Wire affect the phase voltages and currents when the load is unbalanced?

Task 2 B: Three-Phase Measurements with Delta-connected RL Load Box

Table 6: Balanced and unbalanced Delta-connected RL three-phase load.

Measurement	$V_1(rms)\angle\varphi_v$	$I_1(rms)\angle\varphi_i$	$V_2(rms)\angle\varphi_v$	$I_2(rms)\angle\varphi_i$	$V_3(rms)\angle\varphi_v$	$I_3(rms)\angle\varphi_i$	$P_{total}(ave),W$
RL balanced load							
RL unbalanced load, shorted resistor							
RL unbalanced load, shorted inductor							

- How close your measurements are to the ideal case when the RL load is balanced?
- How do the current and power measurements (values) compare with the previous case when the balanced load was Y-connected?
- What happens to the phase voltages and currents when the resistor is shorted in one of the phases?
- What happens to the phase voltages and currents when the inductor is shorted in one of the phases?

Task 2 C: Two Wattmeter Measurement Method with Delta-connected RL Load Box (Canceled for Virtual/Online mode)

Table 7: Two-Wattmeter measurements with Delta-connected RL three-phase load.

Measurement	$V_1(rms)\angle\varphi_v$	$I_1(rms)\angle\varphi_i$	$V_2(rms)\angle\varphi_v$	$I_2(rms)\angle\varphi_i$	$P_1(ave),W$	$P_2(ave),W$	$P_{total}(ave),W$
RL balanced load							
RL unbalanced load, shorted resistor							
RL unbalanced load, shorted inductor							

- The load circuit in Task 2B and Task 2C are identical in each step. Compare the measurements of currents and voltages of Task 2B and Task 2C. Explain the results.

- Compare the measurements of real power of Task 2B and Task 2C. Explain the results.

Task 3 A: Single Phase Full-Wave Rectifier (without and with capacitor filter)

Table 8A: Single phase full-wave rectifier, without capacitor filter.

Measurement # (Load Box Switches)	No Load (no resistor)	Light Load (half of the resistors)	Heavy Load (all resistors) **(save waveforms)**
$V_1(rms), V$			
$I_1(rms), A$			
$P_1(input), W$			
$V_3(rms), V$			
$\Delta V_3(peak-peak), V$			
$I_3(rms), A$			
$\Delta I_3(peak-peak), A$			
$P_3(out), W$			

- What relationship between the voltage and current peak/ripple do you observe?

Table 8B: Single phase full-wave rectifier, <u>with</u> capacitor filter.

Measurement # (Load Box Switches)	No Load (no resistor)	Light Load (half of the resistors)	Heavy Load (all resistors) **(save waveforms)**
$V_1(rms), V$			
$I_1(rms), A$			
$\Delta I_1(peak-peak), A$			
$P_1(input), W$			
$V_3(rms), V$			
$\Delta V_3(peak-peak), V$			
$I_3(rms), A$			
$\Delta I_3(peak-peak), A$			
$P_3(out), W$			

- How do the output voltage and current ripples compare with the previous case without the capacitor filter?

- How does the presence of capacitor impact the input current peak?

- How does the peak of the input current change with the load current?

Task 4: Three Phase Full-Wave Rectifier (without and with capacitor filter)

Table 9A: Three-phase full-wave rectifier, without capacitor filter.

Measurement # (Load Box Switches)	No Load (no resistor)	Light Load (half of the resistors)	Heavy Load (all resistors) **(save waveforms)**
$I_1(rms), A$			
$V_2(rms), V$			
$\Delta V_2(peak-peak), V$			
$I_2(rms), A$			
$\Delta I_2(peak-peak), A$			
$P_3(out), W$			

- What relationship between the voltage and current peak/ripple do you observe?

- How does the input current differ from the single phase rectifier?

Table 9B: Three-phase full-wave rectifier, with capacitor filter.

Measurement # (Load Box Switches)	No Load (no resistor)	Light Load (half of the resistors)	Heavy Load (all resistors) **(save waveforms)**
$I_1(rms), A$			
$\Delta I_1(peak-peak), A$			
$I_2(rms), A$			
$\Delta I_2(peak-peak), A$			
$V_3(rms), V$			
$\Delta V_3(peak-peak), V$			
$I_3(rms), A$			
$\Delta I_3(peak-peak), A$			
$P_3(out), W$			

- How do the output voltage and current ripples compare with the previous case without the capacitor filter?

- How does the presence of capacitor impact the input current peak?

- How do the output voltage and current ripples compare with the single phase rectifier?

- How does the peak of the input current change with the load current?