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 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 a 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 phasor 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.
- Please read and understand this **Lab Manual** before the lab session to become familiar with the specific lab experiments and procedures. Otherwise, you will compromise the performance of your Lab Partner and may not have enough time to complete all your experiments.
- **Bring your Pre-Lab (either hard or soft copy) to your actual Lab and have TA to check it off. You will not be allowed to conduct any experiment without a reasonable Pre-Lab.**

Apparatus & Equipment

This Lab includes the following components:

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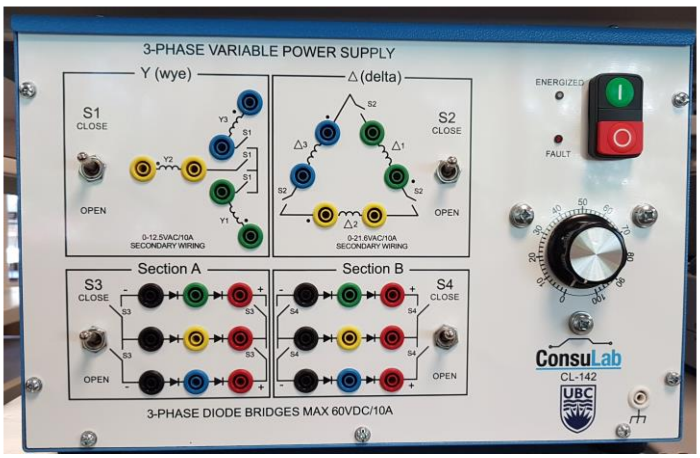
<td>
</td>
<td>3-Phase AC Power Supply: This flexible 3-phase AC/DC Power Supply has two 3-phase transformers inside, one that can readily be configured into a ‘Y’ (wye) connection and the other that can be configured into “Δ” (Delta). The front panel shows the transformer wiring and has several switches 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 autotransformer) 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.</td>
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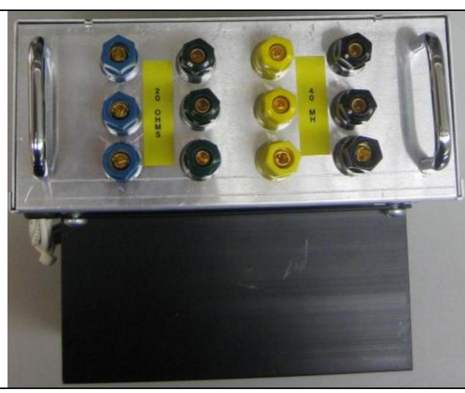
<td>
</td>
<td>RL Load Box: This box contains three 20 Ohms resistors and three 40 mH inductors. These elements can be connected in various ways to implement either a single-phase or three-phase RL load.</td>
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RC Load Box: This box contains three 60 Ohm resistors and three 40 μF capacitors. These elements can be connected in various ways to implement either a 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 rescaled 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 colour-coded. It is strongly recommended that you use appropriate and consistent colour wires for each channel of measurements. This will make it easier for you to wire up your circuits and subsequently check them, finding 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 heat in case a significant amount of power is delivered to the Load. Be careful! This box may get very hot, especially its heat sink, which is located 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 the black terminal is "-" or the ground terminal.

Setting Up the DAQ System

Log in to your local PC and locate the LabVIEW program, **"3-Phase Analysis."** Double-click on the icon and start the program. A window, as 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 the three currents (channels A1, A2, and A3), as needed for either single-phase or three-phase measurements. The measurement window can be triggered using either the 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 unselect the measurement of voltages and currents in Channels 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 measurement process to capture the desired waveforms better and reveal details. The button "**Subtract Zero Sequence**" should be "**OFF**." Remember to push the **ZERO** buttons before each test to remove any offset when measuring currents. The program is also equipped with a digital low-pass filter, featuring an adjustable cut-off frequency, which can be used to filter out high-frequency components of the measured voltages and currents. The Filter should be turned "**OFF**" for this Lab, and you will measure and record actual (unfiltered) voltage and current waveforms.

Setting up Trigger Point: Similar to a conventional Oscilloscope, the program allows triggering the beginning of the measurement window based on Channel 1 signals, either current or voltage. The user can toggle the **Ch1 Trigger Source** switch between Amps and Volts, and slide the **blue** vertical slider on the voltage or current display window.

Displaying Phasors: The program can display all measured voltages and currents as the actual captured Instantaneous Waveforms (default mode), as well as display the corresponding phasors that are computed based on the calculated RMS values and angles of each recorded voltage and current. To display the phasors, simply switch to the **Phasor View** tab.

Saving Recorded Data: The program can **PAUSE** and **SAVE** 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 on any fragment of the recorded window using the **ZOOM** and **POSITION** slide buttons at the bottom of the panel. Pushing the **SAVE** button brings up the window to save the data file. The user should name and save the file in an appropriate location/folder for future analysis.

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

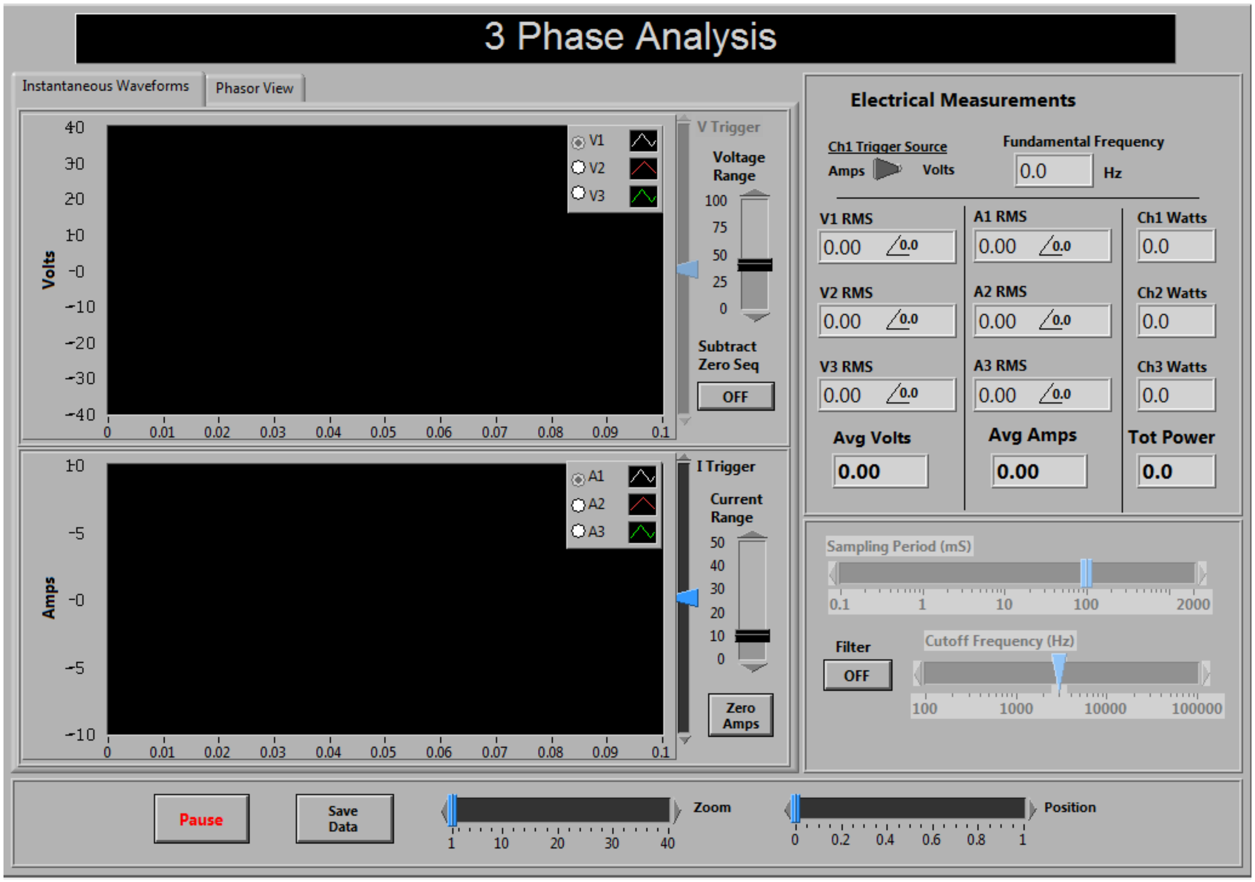

Fig. 1: LabVIEW program interface 3-Phase Analysis.

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.

Use of colored wires: When wiring your circuits, it is generally recommended first to connect all current-carrying cables and components (including the current measurement channels) and then connect the voltmeter channels. Use colour wires consistently with phases and parts of the circuit to minimize the chances of any mistakes!

Note: In each Task, you can verify your calculated phasor diagrams with the Phasor View 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-phase terminals of the Y configuration (with the switch S1 closed) or any of the phases of the Delta configuration (switch S2 can be open) to get the variable output voltage in the range from **0 to 25 V**. You will be using the **RL and RC Load Boxes** to perform several basic single-phase measurements and calculations. You will use the **Measurement Box's** 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 Fig. 2 below. It is a good habit first to connect all current-carrying elements into a complete circuit, and only then connect the voltmeter. Initially, connect only one inductor. You will then use short **red wires** to connect the other inductors in parallel. Make sure that your current and voltage meters have the correct relative polarity, as shown in Fig. 2. Otherwise, some of your measurements may be 180 degrees out of phase.

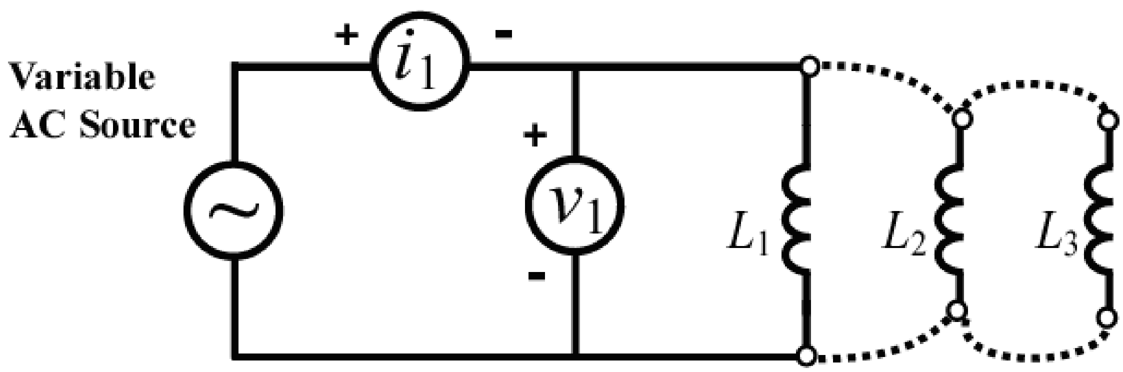

Fig. 2: Single-phase parallel inductors wiring diagram.

2) Turn on the **3-phase AC Power Supply** and slowly increase the applied voltage to approximately 15-17 V. The TA may give you the exact voltage level. 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 Table 1.
4) Turn off the **3-Phase AC Power Supply,** then connect all the inductors in parallel.
5) Turn on the **3-Phase AC Power Supply** and record the new measurements in Table 1.
6) Using the relationships in your **Pre-Lab page**, calculate the resulting equivalent impedance Z, equivalent inductance L, and equivalent series resistance R for the two cases.
7) Switch to displaying the measurements in **Phasor View**. Screen capture it for future use and discussions.

8) Turn off the **3-Phase AC Power Supply!**

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.

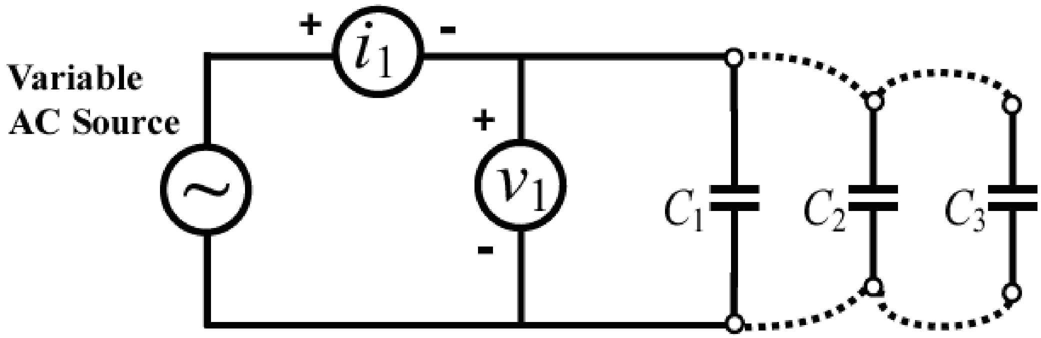

Fig. 3: Single-phase parallel capacitors wiring diagram.

2) Turn on the **3-phase AC Power Supply** and slowly increase the applied voltage to approximately 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 Table 2.
4) Turn off the **3-Phase AC Power Supply,** then connect all the capacitors in parallel.
5) Turn on the **3-Phase AC Power Supply** and record the new measurements in Table 2.
6) Using the relationships in your **Pre-Lab page**, calculate the resulting equivalent impedance Z, equivalent capacitance C, and equivalent parallel resistance R for the two cases.
7) Switch to displaying the measurements in **Phasor View**. Screen capture it for future use and discussions.
8) Turn off the **3-Phase AC Power Supply!**

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 one 20 Ohm resistor from the **RL Load Box** to the measurement circuit for Channel 1 to measure V1 and A1, as shown in Fig. 4. Then, connect an inductor and a capacitor in parallel to the resistor, each with a current meter in series, as illustrated below.

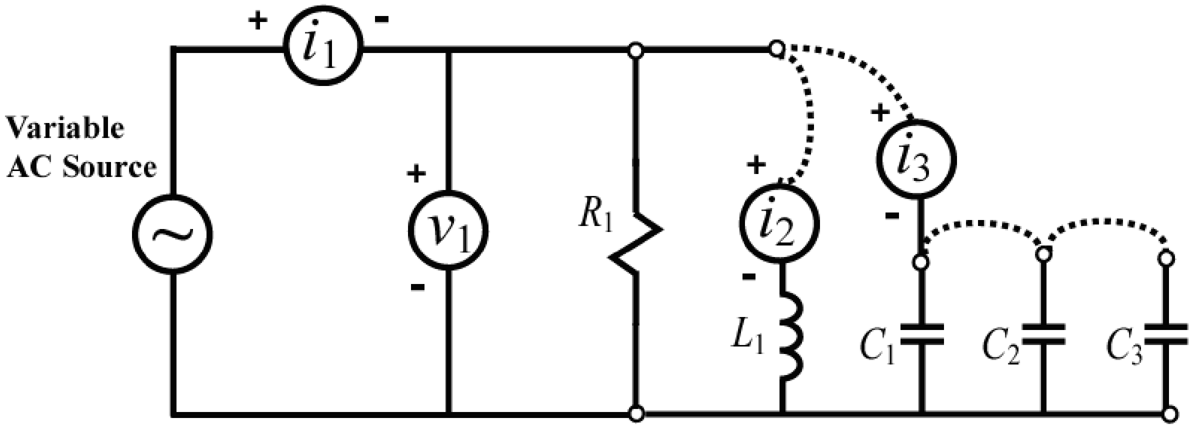

Fig. 4: Wiring diagram of parallel connection of RLC components.

2) Turn on the **3-Phase AC Power Supply** and slowly increase the 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 a single resistor from the **RL Load Box** being supplied by 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 Table 3. Also, **PAUSE** and **SAVE** these measured waveforms. You will then use these recorded waveforms to calculate the instantaneous power, real power, and reactive power, and to plot the results in your Lab report.
4) Then connect the inductor in parallel to the resistor. Record the second set of measurements in Table 3. Also, **PAUSE** and **SAVE** these measured waveforms for future calculations.
5) Leave the inductor connected. Then, connect all three capacitors in parallel to the inductor (the capacitors should be in parallel themselves), and record the measurements in Table 3. Also, **PAUSE** and **SAVE** these measured waveforms for future calculations.
6) Switch to displaying the measurements in **Phasor View**. Screen capture it for future use and discussions.
7) Turn off the **3-Phase AC Power Supply!**

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.

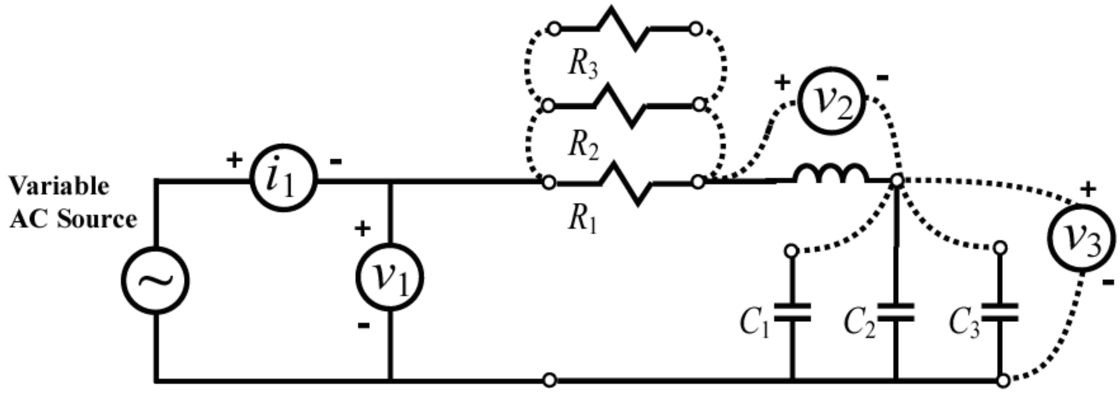

Fig. 5: Wiring diagram of the series connection of RLC components.

2) Turn on the **3-Phase AC Power Supply** and slowly increase the applied voltage to about 15 - 17 V**. The TA may specify the exact voltage level**. 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 the **RL Load Box** and one capacitor from the **RC Load Box,** all connected in series and supplied from the AC source. Record the first set of measurements in Table 4.
4) The subsequent 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 Table 4. Also, **SAVE** the measured waveforms for future calculations. You will then use the recorded waveforms to calculate the instantaneous power, real power, and reactive power, and to plot the results in your Lab report.
6) Switch to displaying the measurements in **Phasor View**. Screen capture it for future use and discussions.
7) Turn off the **3-Phase AC Power Supply!**

You will then use the recorded waveforms to calculate the instantaneous power, real power, and reactive power, and to plot 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 use the **RL** and **RC Load Boxes** to perform several basic three-phase measurements and calculations. You will use the **Measurement Box** to display the voltages V1, V2, V3, and currents A1, A2, A3 in all three channels of 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 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 Fig. 6 below. Ensure that your current and voltage meters have the correct relative polarity, as shown in Fig. 6. Alternatively, some of your measurements may be 180 degrees out of phase. 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.

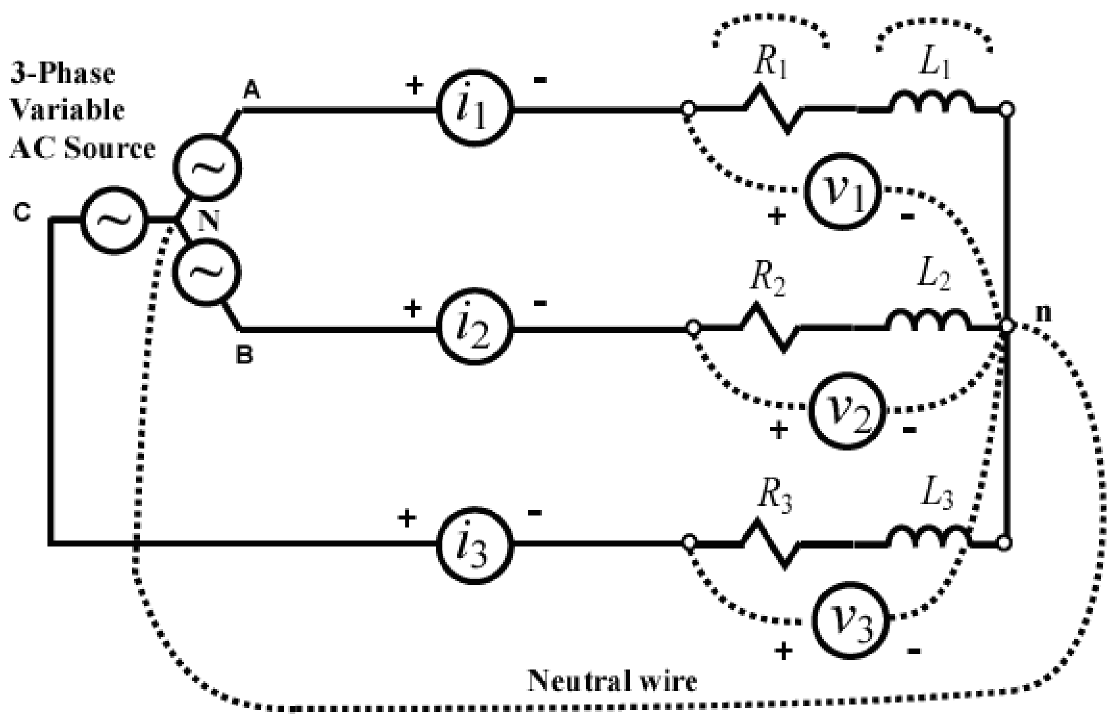

Fig. 6: Three-phase Y-connected RL load wiring diagram.

2) Turn on the **3-Phase AC Power Supply** and slowly increase the applied phase voltage to a level of 10-12 V. The exact voltage level may be specified 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 Table 5. Write down the RMS value and the angle of each voltage and current. Also, record the measured waveforms for future calculations using the **PAUSE** and **SAVE** buttons. Switch to displaying the measurements in **Phasor View**. Screen capture it for future use and discussions.
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 using the **PAUSE** and **SAVE** buttons. Switch to displaying the measurements in **Phasor View**. Screen capture it for future use and discussions.
5) Connect the Neutral Wire between the source and the Load. Repeat step 4) and record the measured waveforms of the last measurement with the shorted inductor for future calculations using the **PAUSE** and **SAVE** buttons. Switch to displaying the measurements in **Phasor View**. You can screen capture it for future use and discussions.

6) Do you observe the expected relationships for each case? You will need to explain the corresponding phasor diagrams in your report.
7) Turn off the **3-Phase AC Power Supply!**

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

1) Wire the circuit shown in Fig. 7 below using the ***RL* Load Box**. First, connect only the current measurement circuit and the Delta-connected RL load. Then, connect the voltmeter channels to form a floating neutral point. You will then use short red wires to bypass (short-circuit) elements in one of the phases. Ensure that your current and voltage meters have the correct relative polarity, as shown in Fig. 7. Alternatively, some of your measurements may be 180 degrees out of phase.

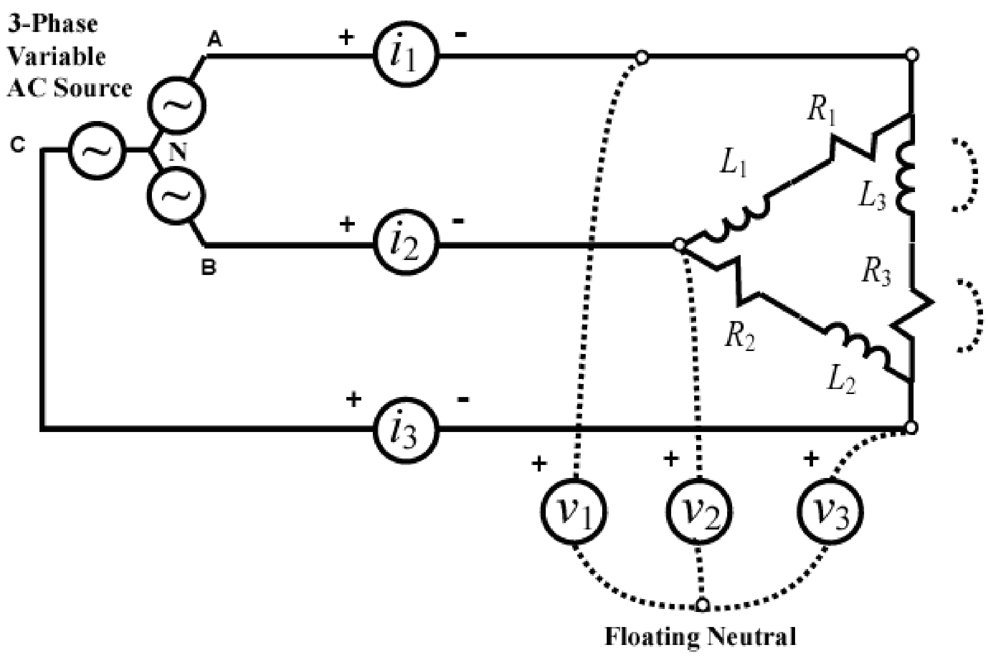

Fig. 7: Three-phase Delta-connected RL load wiring diagram.

2) Turn on the **3-Phase AC Power Supply** and slowly increase the 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.
8) Record the first set of measurements in Table 6. Write down the RMS value and the angle of each voltage and current. Switch to displaying the measurements in **Phasor View**. Screen capture it for future use and discussions.
3) 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. Switch to displaying the measurements in Phasor View and screen capture it for future use and discussions.

4) Then, remove the short, and now repeat the same test with the shorted inductor in the same phase. Again, record the measurements in Table 6. Switch to displaying the measurements in Phasor View and screen capture it for future use and discussions.
5) Do you observe the expected relationships for each case? You will need to explain the corresponding phasor diagrams in your report.
6) Turn off the **3-Phase AC Power Supply!**

Task 2 C: Two-Wattmeter Measurement Method with Delta-connected RL Load Box (Optional, for bonus points, if time permits)

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 the voltage channel (V3). This method of measurement 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.

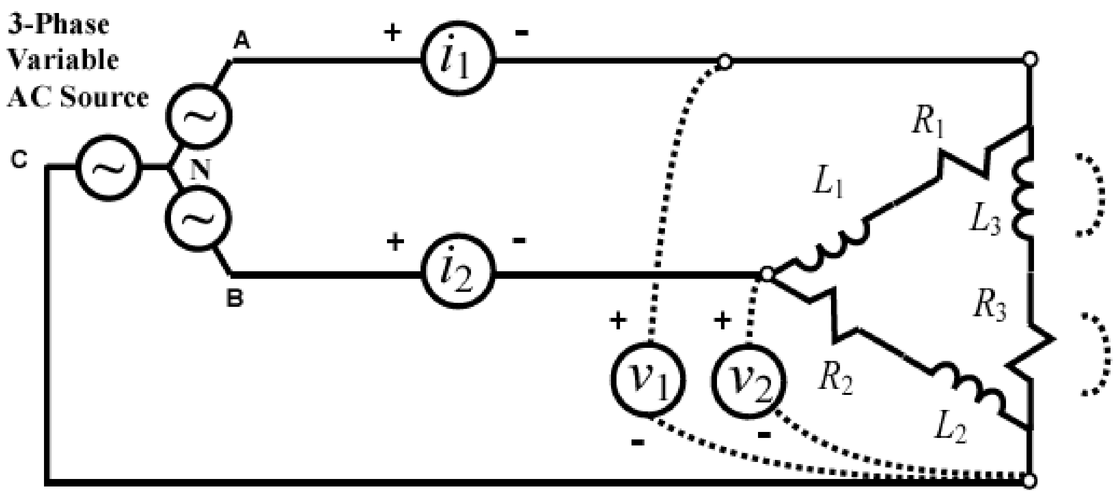

Fig. 8: Three-phase delta-connected RL load with two-wattmeter method.

2) Turn on the **3-Phase AC Power Supply** and slowly increase the 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 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. Ensure that, before each test, the Knob of the **Variac** on the front panel is turned all the way to zero. You will use the diodes on the power supply's front panel to configure the full-wave rectifier. You will be using the **Load Resistor Box** to implement a variable load and the **Capacitor Box** to filter the DC voltage ripple. You will use the **Measurement Box** and all three of its channels to display the voltages V1, V2, V3, and currents A1, A2, and A3 in your circuits. Using the wires available on your bench, you will need to wire up 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, consisting of A1, A3, and four diodes, to form a bridge. Then, connect the **Capacitor Box** and the **Load Box**. Then connect the voltmeter channels V1 and V3.

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

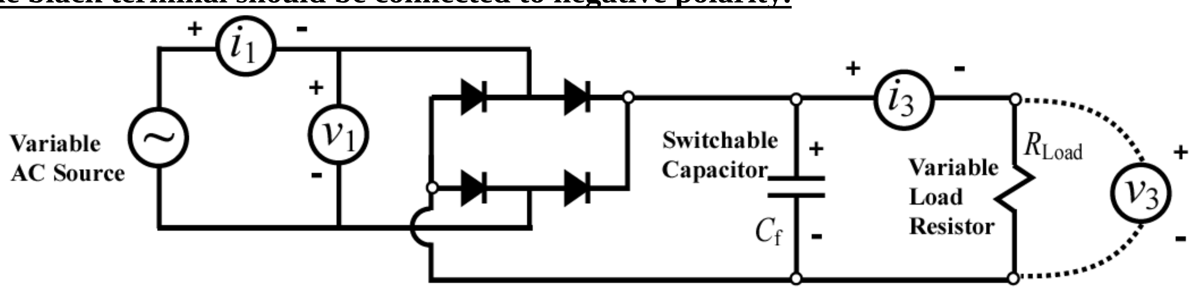

Fig. 9: Single-phase full-wave rectifier wiring diagram.

2) Turn on the **3-Phase AC Power Supply** and slowly increase the applied voltage using the Variac knob to the level of approximately 12 to 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) We will now test the circuit **without** the capacitor filter. Initially, all capacitors in the **Capacitor Box** and all 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 resistors 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 directions due to the full-wave rectification.
4) We will now test the circuit **with** the capacitor filter in place. Initially, all 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 resistors 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 cause the input current to have a 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 the **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, the **Capacitor Box**, and the **Load Box**. Then connect the voltmeter channels V1, V2 and V3.

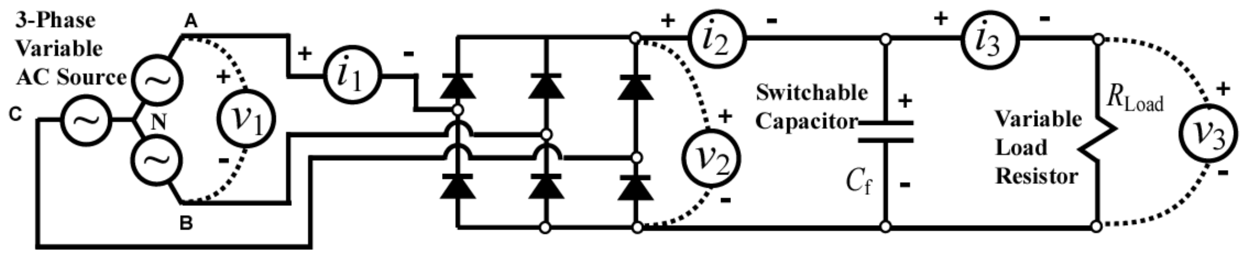

Fig. 10: Three-phase full-wave rectifier wiring diagram.

2) Turn on the **3-Phase AC Power Supply** and slowly increase the applied voltage to 10 V. The TA may specify the exact voltage level. 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 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 resistors 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 – they have smaller ripple than in the case of a single-phase rectifier.
4) We will now test the circuit **with** the capacitor filter. Initially, all 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, making it appear more like DC. You will then switch ON half of the resistors in the **Load Box** (light load condition). Finally, switch ON all the resistors 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 very significant spikes/peaks. The value of this spike may be significantly higher than the output DC current! Additionally, use the **PAUSE** and **SAVE** buttons to record the measured waveforms for the last measurement,

with all load resistors connected. This may be used 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 strongly encouraged to use MATLAB or Excel (or an equivalent powerful tool) for performing calculations, plotting the recorded and calculated waveforms, and creating phasor diagrams. Properly label all the plot axes, including the units on all plots and phasor diagrams. You can also include screenshots of your phasors from your experiments, as appropriate, to support your explanations.

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 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 a 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 do 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 process for the measurements of Steps 4 and 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 the case of an unbalanced Load if the load phases are connected in Delta as in Task 2B? Explain your findings based on the measurements in 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 used appropriately. You will need to rescale the output of the FFT to display the harmonic spectrum correctly!

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

Optional (for bonus marks): Try using the Simulink toolbox Simscape Electrical to reproduce the system in 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 the similarities 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 26 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 from 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 the Canvas system for this course before the stated deadline.
Name your file as YourName_yourID_LabX_report.pdf

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 a 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 a 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 are your measurements 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 are your measurements 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 (Optional, for bonus points)

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 is identical in each step. Compare the measurements of currents and voltages of Task 2B and Task 2C. Explain the results.

- Compare the measurements of the 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, <u>without</u> a 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, with 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 a 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, <u>without</u> 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 that of the single-phase rectifier?

Table 9B: Three-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)**
$I_1(rms), A$			
$\Delta I_1(peak-peak), A$			
$I_2(rms), A$			

$\Delta I_2(peak-peak), A$			
$V_3(rms), V$			
$\Delta V_3(peak-peak), V$			
$I_3(rms), A$			
$\Delta I_3(peak-peak), A$			
$P_3(out), W$			

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

- How does the presence of a 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?