ELEC 342

Lab Experiment: AC/DC Circuits and Basic Measurements

Section: L1B & L1D

Bench #: (At Home)

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1. Data and Parameters

1.1A Task 1 A: Measurements with RL Load Box

f = 60 Hz

Measurement	V1 (rms), V	I1 (rms), A	Phase 1	P1 (ave), W	Z, Ω	R, Ω	L, H
one inductor	17.20	0.90	85.8	1.1	18.5426	1.3580	0.04905
three inductors	17.14	2.63	85.7	3.4	6.5559	0.4915	0.01734

Table 1: Single Phase Parallel Inductors

- **How is this inductor different from an ideal inductor element?**

  This inductor has a built-in resistance in series where an ideal inductor has no resistance. There is no power dissipated in an ideal inductor as R=0, and therefore has zero power loss.

- **Are the calculated values of inductance close to the expected value? What is the difference?**

  The expected value of an inductor is 40 mH. It is very close to the calculated value which is 49 mH. The difference between the calculated value and the expected value is 9 mH which is very small and may be caused by calculation roundings and small fluctuations when taking measurements.

1.1B Task 1 B: Measurements with RC Load Box

f = 60 Hz

Measurement	V1 (rms), V	I1 (rms), A	Phase 1	P1 (ave), W	Z, Ω	R, Ω	C, F
one capacitor	21.51	0.36	-89.6	0.05	55.2626	0.3858	0.000048
three capacitors	21.51	1.08	-89.8	0.05	12.2805	0.04287	0.000216

Table 2: Single phase parallel capacitors

- **How is this capacitor different from an ideal capacitor element?**

  This capacitor has a built-in resistance in parallel where an ideal capacitor does not have resistance. There is no power dissipated in an ideal capacitor as R=0, and therefore has zero power loss.

- **Are the calculated values of capacitance close to the expected value? What is the difference?**

  The expected value of the capacitance is 40 microfarads where the calculated value is 48 microFarads. The difference between the two is 8 microfarads which is almost negligible.

1.1C Task 1 C: Parallel connection of RLC components

Supply voltage V1 = 21.31(rms)∠-0.5

Measurement	I1 (rms), A	Phase 1	I2 (rms), A	Phase 2	I3 (rms), A	Phase 3	P1 (avg), W
one resistor R1	1.02	0	X	X	X	X	20.6
R1 and L1	1.56	45.3	1.12	85.8	X	X	22.3
R1, L1, C1+C2+C3	1.19	9.5	0.44	64.1	1.01	-89.6	22.6

Table 3: Parallel connection of RLC components

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

  The real power increased by around 2W when inductors and capacitors were connected in parallel.

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

  The sum of the magnitude of each individual branch current I2, and I3 is equal to the total circuit current I1.

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

  No, neither I2 or I3 can have magnitudes larger than the magnitude of I1 since I1 is the total current where I2 and I3 are branch currents, branch currents cannot be larger than the total current.

1.1D Task 1 D: Series connection of RLC components

Supply voltage V1 = 15.06(rms)∠-0.4

Measurement	I1 (rms), A	Phase 1	V2 (rms), V	Phase 2	V3 (rms), V	Phase 3	P1 (avg), W
R1, L1, C1	0.32	-60.3	8.15	-143.9	21.07	29.4	2.4
R1, L1, C1+C2+C3	0.69	-2.6	14.41	- 87.6	15.05	87.0	10.3
R1, R2, R3, L1, C1+C2+C3	1.60	-32.2	26.9	-118.1	34.94	57.5	20.3

Table 4: Series connection of RLC components.

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

  The real power increased by a fair amount when capacitors and resistors were connected in parallel.

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

  The sum of the magnitude of the individual voltage drops due to each individual element in series is equal to the total voltage applied to the circuit.

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

  No, V2 and/or V3 cannot have a magnitude larger than the magnitude of V1 as voltage drops through each element in series.

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

Task 1D Step 5 Phasor Diagram

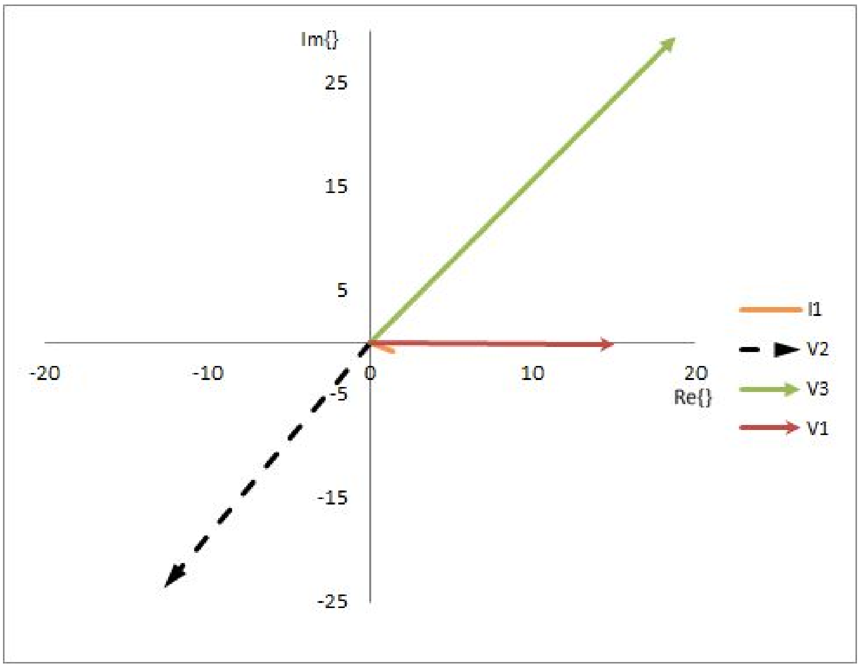

Figure 1.1: Phasor Diagram Task 1 D Step 5

1.2A Task 2 A: Three-Phase Measurements with Y-connected RL Load Box

Measurement	V1 (rms) ∠V	I1 (rms) ∠I1	V2 (rms) ∠V	I2 (rms) ∠I1	V3 (rms) ∠V	I3 (rms) ∠I1	Ptotal (avg), W
RL balanced load, neutrals disconnected **(save waveforms)**	12.08∠1	0.36 ∠-46	12.02 ∠-120	0.38 ∠194	12.3 ∠119	0.37 ∠71	9.0
RL unbalanced load, shorted resistor, neutrals disconnected	11.5 ∠2.7	0.49 ∠-82	10.52 ∠213	0.33 ∠166.9	15.35 ∠104	0.48 ∠59	8.2
RL unbalanced load, shorted inductor, neutrals disconnected **(save waveforms)**	10.6 ∠-2.6	0.53 ∠-2.9	16.05 ∠-103	0.52 ∠212	10.67 ∠154	0.32 ∠106	13.6
RL unbalanced load, shorted resistor, neutrals connected	12.03 ∠-3	0.54 ∠-88	12.11 ∠-123	0.38 ∠190	12.11 ∠116	0.37 ∠68	6.8
RL unbalanced load, shorted inductor, neutrals connected **(save waveforms)**	12.0 ∠-3.2	0.6 ∠-3.2	12.16 ∠1.2	0.38 ∠190	12.12 ∠116	0.37 ∠69	13.4

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

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

  The magnitude of voltages and currents in the unbalanced cases are similar to the ones in the ideal case.

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

  When the resistor is shorted in one of the phases, the current for I1(rms) no lags even more behind the phase voltage V1(rms). The other currents and voltages show little change in relation apart from a general decrease in phase.

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

  When the inductor is shorted in one of the phases, the current for I1(rms) no longer lags behind the phase voltage V1(rms). The other currents and voltages show little change in relation.

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

  With an unbalanced load, the line currents do not balance out, and left over current will be carried back to the supply. Without a neutral wire, instabilities can occur without a neutral wire such as unstable voltage or current.

1.2B Task 2 B: Three-Phase Measurements with Delta-connected RL Load Box

Measurement	V1 (rms) ∠V	I1 (rms) ∠I1	V2 (rms) ∠V	I2 (rms) ∠I1	V3 (rms) ∠V	I3 (rms) ∠I1	Ptotal (avg), W
RL balanced load	12.18 ∠-3	1.12 ∠-46	12.26 ∠-123	1.23 ∠194	12.22 ∠116	1.24 ∠73	32.8
RL unbalanced load, shorted resistor	12.18 ∠-3	1.85 ∠-65	12.35 ∠-123	1.25 ∠156	12.25 ∠116	1.25 ∠72	24
RL unbalanced load, shorted inductor	11.98 ∠-3.2	1.1 ∠-11	11.99 ∠-1.2	1.72 ∠213	12.05 ∠117	1.22 ∠73	42.7

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

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

  The magnitude of voltages and currents in the unbalanced cases are similar to the ones in the ideal case.

- **How do the current and power measurements (values) compare with the previous case when the balanced load was Y-connected?**

  Currents in the Delta connection are larger than currents in the Wye connection. Power in the Delta connection is also larger than the power in the Wye connection.

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

  When the resistor is shorted in one of the phases, the phase difference between voltage V1 and current I1 increases by around 20 degrees where the phase differences between voltages and currents in the other two phases are roughly the same.

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

  When the inductor is shorted in one of the phases, the phase difference between voltage V1 and current I1 decreases where the phase difference between voltage V2 and current I2 increases. Voltage V3 and current I3 remain the same.

1.3A Task 3 A: Single Phase Full-Wave Rectifier (without and with capacitor filter)

Measurement # (Load Box Switches)	No Load (no resistor)	Light Load (half of the resistors)	Heavy Load (all resistors) **(save waveforms)**
V1 (rms), V	20.19	20.06	20.07
I1 (rms), A	0	1.12	2.02
P1 (input), W	0	22	40.2
V3 (rms), V	19.56	18.54	18.38
dV3 (peak-peak), V	55.32	52.44	51.99
I3 (rms), A	0	1.17	2.08
dI3 (peak-peak), A	0	3.31	5.88
P3 (out), W	0	21.7	38.2

Table 8A: Single phase full-wave rectifier, <u>without</u> capacitor filter.

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

  For the third phase, peak to peak voltages gradually decrease when the load is added. Instead, peak to peak currents increase when more load is added.

Measurement # (Load Box Switches)	No Load (no resistor)	Light Load (half of the resistors)	Heavy Load (all resistors) **(save waveforms)**
V1 (rms), V	20.48	20.13	20.16
I1 (rms), A	0	2.63	4.32
dI1 (peak-peak), A	0	7.44	12.22
P1 (input), W	0	38.3	67
V3 (rms), V	26.91	24.06	23.24
dV3 (peak-peak), V	76.11	68.05	65.73
I3 (rms), A	0	1.52	2.63
dI3 (peak-peak), A	0	4.30	7.44
P3 (out), W	0	36.5	61.1

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

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

  In general, peak to peak voltages and currents are larger in the case with the capacitor filter than those without the capacitor filter. The trend of peak to peak voltages decreasing and peak to peak currents increasing when more load is added still follows.

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

  The input current peak increases when a capacitor is added in parallel with the load since part of the input current goes through the capacitor.

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

  The peak of input current increases when the peak of load current increases.

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

Measurement # (Load Box Switches)	No Load (no resistor)	Light Load (half of the resistors)	Heavy Load (all resistors) **(save waveforms)**
I1 (rms), A	0	1.23	2.19
V2 (rms), V	26.17	25.05	24.64
dV2 (peak-peak), V	74.02	70.85	69.69
I2 (rms), A	0	1.58	2.78
dI2 (peak-peak), A	0	4.47	7.86
P3 (out), W	0	37.5	66.0

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

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

  For the second phase, peak to peak voltages gradually decrease when the load is added. Instead, peak to peak currents increase when more load is added.

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

  In comparison with the single phase full-wave rectifier without capacitor filter, the input currents increase in three-phase by a little.

Measurement # (Load Box Switches)	No Load (no resistor)	Light Load (half of the resistors)	Heavy Load (all resistors) **(save waveforms)**
I1 (rms), A	0	1.4	2.31
dI1 (peak-peak), A	0	3.96	6.53
I2 (rms), A	0	2.86	2.94
dI2 (peak-peak), A	0	8.09	8.32
V3 (rms), V	26.6	25.1	24.6
dV3 (peak-peak), V	75.24	70.99	69.58
I3 (rms), A	0	1.5	2.12
dI3 (peak-peak), A	0	4.24	6.00
P3 (out), W	0	37.9	66.5

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

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

  Output voltage ripples in the case with capacitor filter are approximately the same as the ones without capacitor filter. Current ripples are larger in the case with capacitor filter than in the case without capacitor filter.

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

  The input current peak is slightly higher with the presence of a capacitor since there is also some current going through the capacitor causing the total input current to be larger.

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

  In comparison with the single phase full-wave rectifier with capacitor filter, the output voltage and current ripples are approximately the same.

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

  The input current increases when the load current increases as if one of the branch currents increases, the total current will also increase.

2. Calculation and Analysis

2.1 Task 1 A: Measurements with RL Load Box

- **Table 1: Single Phase Parallel Inductors**
    - Finding Impedance: $Z = \frac{P}{I^2 * cos(\varphi)}$
    - Finding Resistance: $R = \frac{P}{I^2}$
    - Finding Inductance: $L = \frac{R * tan(\varphi)}{\omega}$ where $\omega = 2 * \pi * f = 120 * \pi$

2.2 Task 1 B: Measurements with RC Load Box

- **Table 2: Single Phase Parallel Capacitors**
    - Finding Impedance: $Z = \frac{P}{I^2 * cos(\varphi)}$
    - Finding Resistance: $R = \frac{P}{I^2}$
    - Finding Capacitance: $C = \frac{1}{R * tan(\varphi) * \omega}$ where $\omega = 2 * \pi * f = 120 * \pi$

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

- **Table 8A: Single phase full-wave rectifier, <u>without</u> capacitor filter.**
    - Finding dV(peak-peak): $dV = V(rms) * 2 * \sqrt{2}$

- **Table 8B: Single phase full-wave rectifier, <u>with</u> capacitor filter.**
    - dV(peak-peak): $dV = V(rms) * 2 * \sqrt{2}$
    - dI(peak-peak): $dI = I(rms) * 2 * \sqrt{2}$

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

- **Table 9A: Three-phase full-wave rectifier, <u>without</u> capacitor filter.**
    - dV(peak-peak): $dV = V(rms) * 2 * \sqrt{2}$
    - dI(peak-peak): $dI = I(rms) * 2 * \sqrt{2}$

- **Table 9B: Three-phase full-wave rectifier, <u>with</u> capacitor filter.**
    - dI(peak-peak): $dI = I(rms) * 2 * \sqrt{2}$

2.5A 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.**
  - Instantaneous Power: $P = V * I$
    - $= (21.31\angle -0.5) * (2.03\angle 0) = 43.36\angle -0.5VA$
  - Real Power: $P = I^2 * R = |I| * |V| * cos(\varphi) = RE(S),\ \varphi = \varphi v - \varphi i$
    - $= 1.02 * 21.31 * cos(-0.5) = 21.74W$
  - Reactive Power: $Q = I^2 * X = |I| * |V| * sin(\varphi) = IM(S),\ \varphi = \varphi v - \varphi i$
    - $1.02 * 21.31 * sin(-0.5) = 0.18968VAR$

- **Plot your results on separate subplots such that you can clearly see all calculated powers one after another**

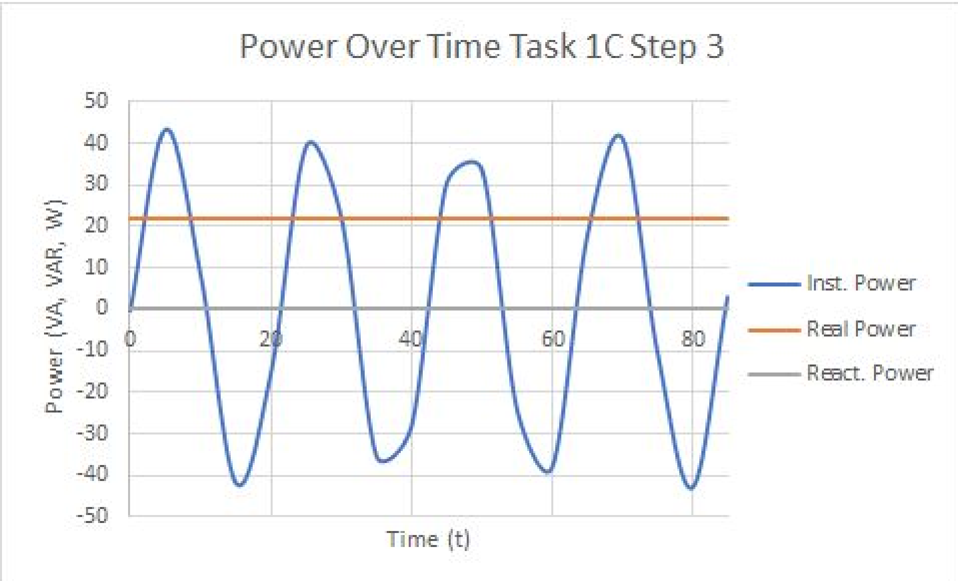

Figure 1.2 Task 1C Step 3 Power Over Time

- **Repeat similar calculations for the data recorded in Task 1C, Steps 4 and 5**
  - Instantaneous Power: $P = V * I$
    - Step 4: $= (21.31\angle -0.5) * (1.56\angle 45.3) = 33.2436\angle 44.8VA$
    - Step 5: $= (21.31\angle -0.5) * (1.19\angle 9.5) = 25.36\angle 9VA$
  - Real Power: $P = I^2 * R = |I| * |V| * cos(\varphi) = RE(S),\ \varphi = \varphi v - \varphi i$
    - Step 4: $= 1.56 * 21.31 * cos(-0.5 - 45.3) = 23.3W$
    - Step 5: $= 1.19 * 21.31 * cos(-0.5 - 9.5) = 24.97W$
  - Reactive Power: $Q = I^2 * X = |I| * |V| * sin(\varphi) = IM(S),\ \varphi = \varphi v - \varphi i$
    - Step 4: $= 1.56 * 21.31 * sin(-0.5 - 45.3) = 23.71VAR$
    - Step 5: $= 1.19 * 21.31 * sin(-0.5 - 9.5) = 4.40VAR$

- **Plot the instantaneous, real, and reactive power**

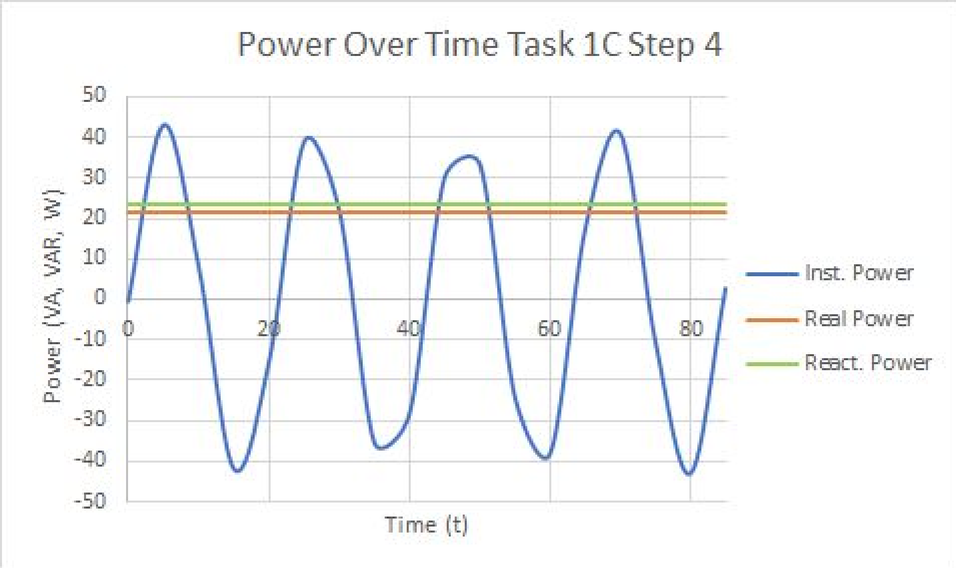

Figure 1.3 Task 1C Step 4 Power Over Time

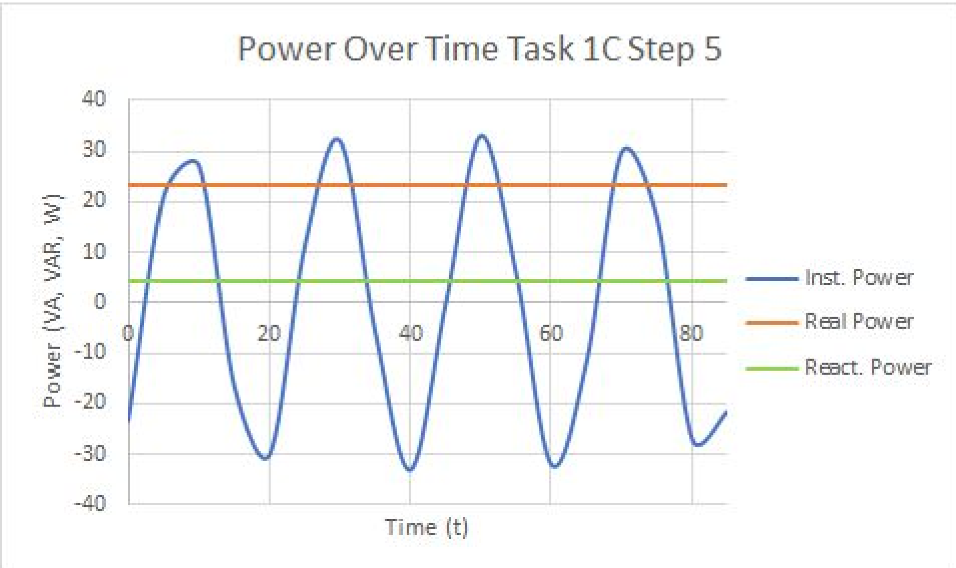

Figure 1.4 Task 1C Step 5 Power Over Time

- **Explain the meaning of instantaneous, real, and reactive power**
    - Instantaneous power (p) is the amount of power in a circuit at any instant of time.
    - Real power (P) is the active power that performs work in Watts within an electrical circuit, and is consumed by the resistive component of a circuit.
    - Reactive power (Q) is the power consumed in an AC circuit that does not perform any useful work, and is linked to reactance produced by inductors and capacitors.

- **How has adding an inductor and capacitors in your case changed the reactive and real power that you have measured in this task?**

  The Real power has remained approximately the same while the reactive power has considerably increased as reactive components were added to the circuit.

- **Based on the measurement in Task 1C, Step 5, draw 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 1C Step 5 Phasor Diagram

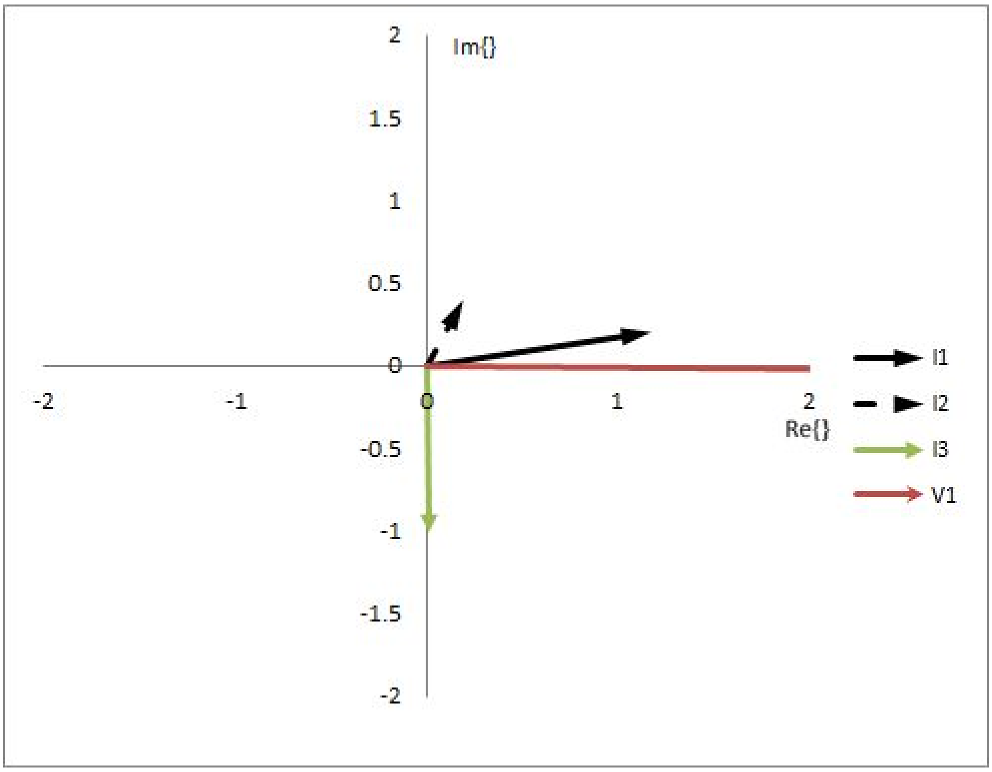

Figure 5.3: Task 1C Step 5 Phasor Diagram

2.5B Task 5 B: Single-Phase Phasor Diagram for the Series RLC Circuit

- **Based on the measurement in Task 1D, Step 4, draw the phasor diagram for this case showing the applied voltage V1, the input current I1, the inductor voltage V2 and the capacitor voltage V3**

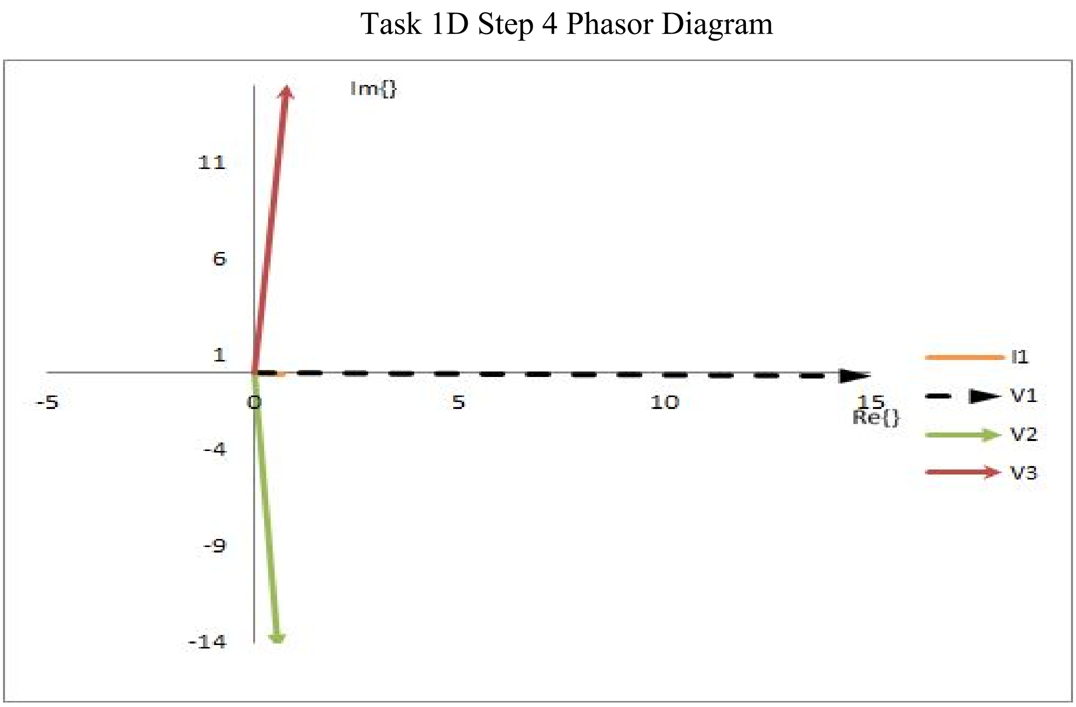

Figure 5.4: Task 1D Step 4 Phasor Diagram

- **Repeat the same for the measurement of Step 5**

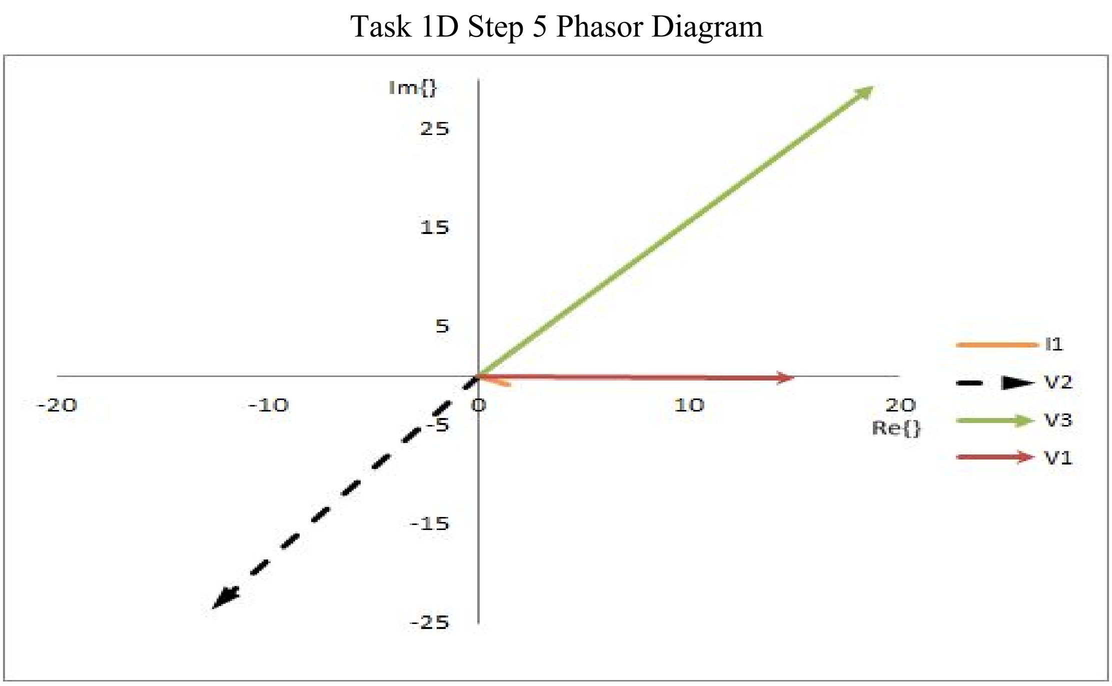

Figure 5.5: Task 1D Step 4 Phasor Diagram

- **Based on your diagrams, how does the voltage across the inductor and capacitor relate to the applied voltage?**

  If the applied voltage V1 is taken as a reference, the inductor voltage V2 is lagging by 90 degrees, and the capacitor voltage V3 is leading by 90 degrees.

2.5C Task 5 C: Three-Phase Phasor Diagrams for Wye-connected RL Load

- **Based on the measurement in Task 2A, Step 3, draw the phasor diagram for this case showing the applied phase voltages V1, V2, V3, and input currents I1, I2, I3**

Task 2A Step 3 Voltages Phasor Diagram

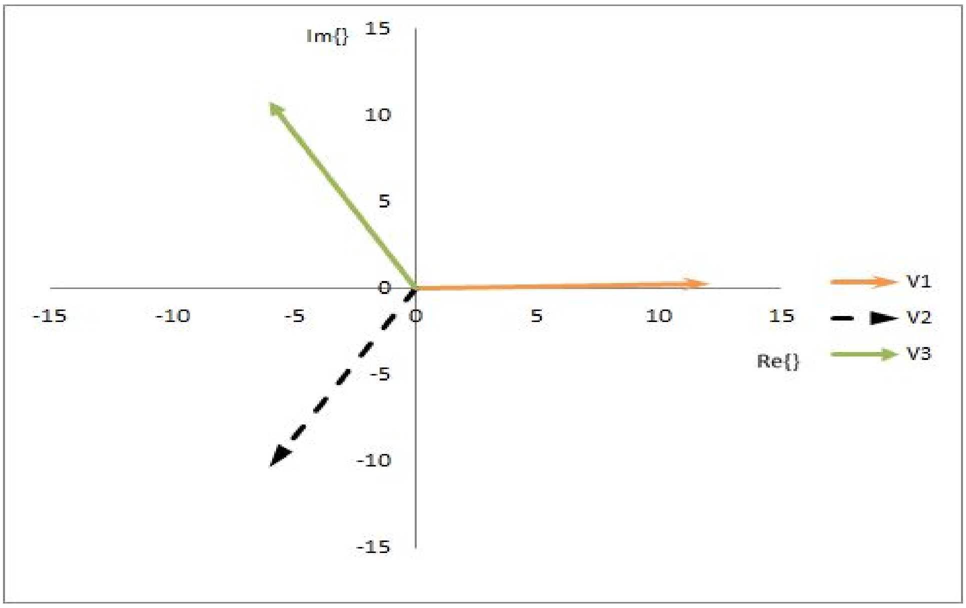

Figure 5.6: Task 2A Step 3 Voltages Phasor Diagram

Task 2A Step 3 Currents Phasor Diagrams

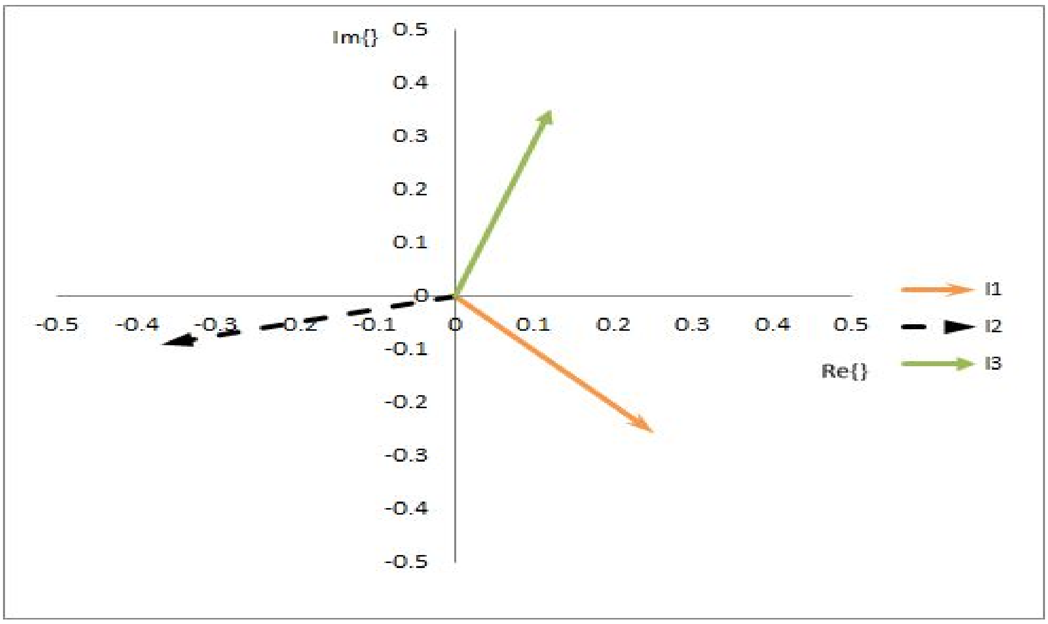

Figure 5.7: Task 2A Step 3 Currents Phasor Diagram

- **Repeat the same for the measurement of Step 4 and Step 5**

Task 2A Step 4-5 Shorted R, Neutrals Connection Voltage Comparison

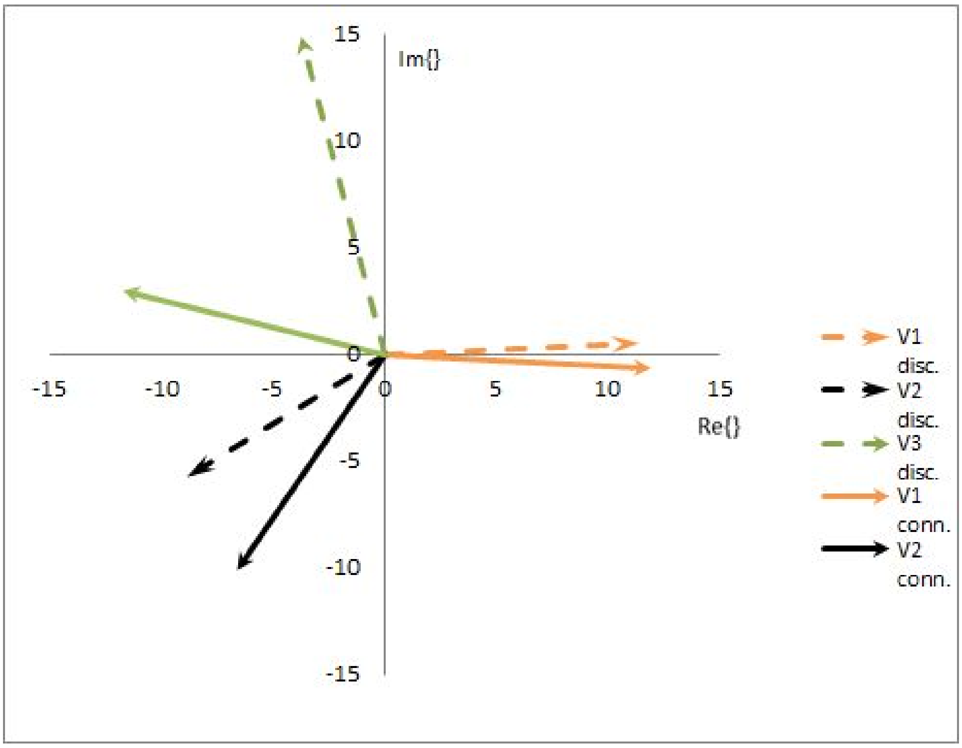

Figure 5.8: Task 2A Step 4-5 Shorted R, Neutrals Connection V Comparison

Task 2A Step 4-5 Shorted R, Neutrals Connection Current Comparison

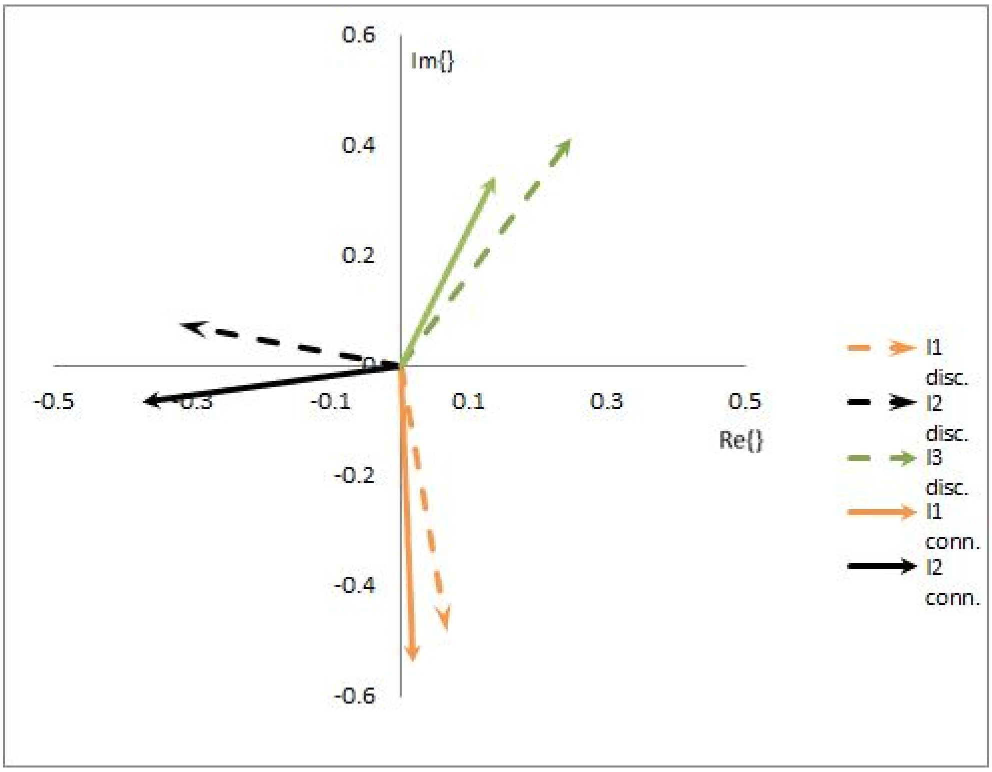

Figure 5.8: Task 2A Step 4-5 Shorted R, Neutrals Connection I Comparison

Task 2A Step 4-5 Shorted L, Neutrals Connection Voltage Comparison

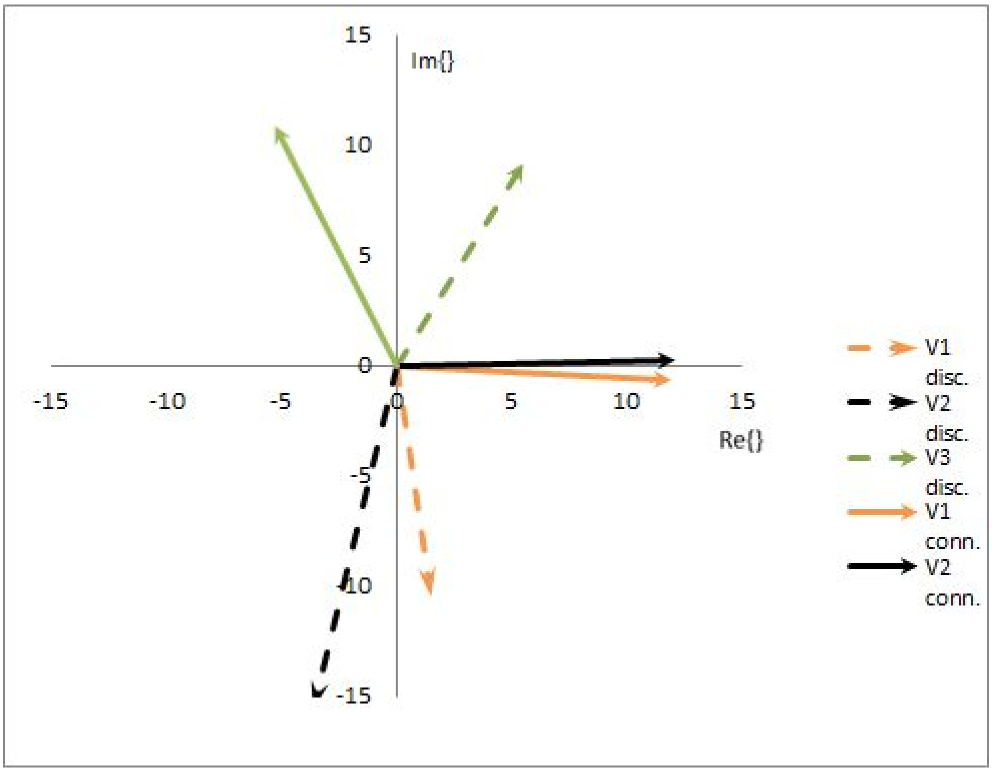

Figure 5.8: Task 2A Step 4-5 Shorted L, Neutrals Connection V Comparison

Task 2A Step 4-5 Shorted L, Neutrals Connection Current Comparison

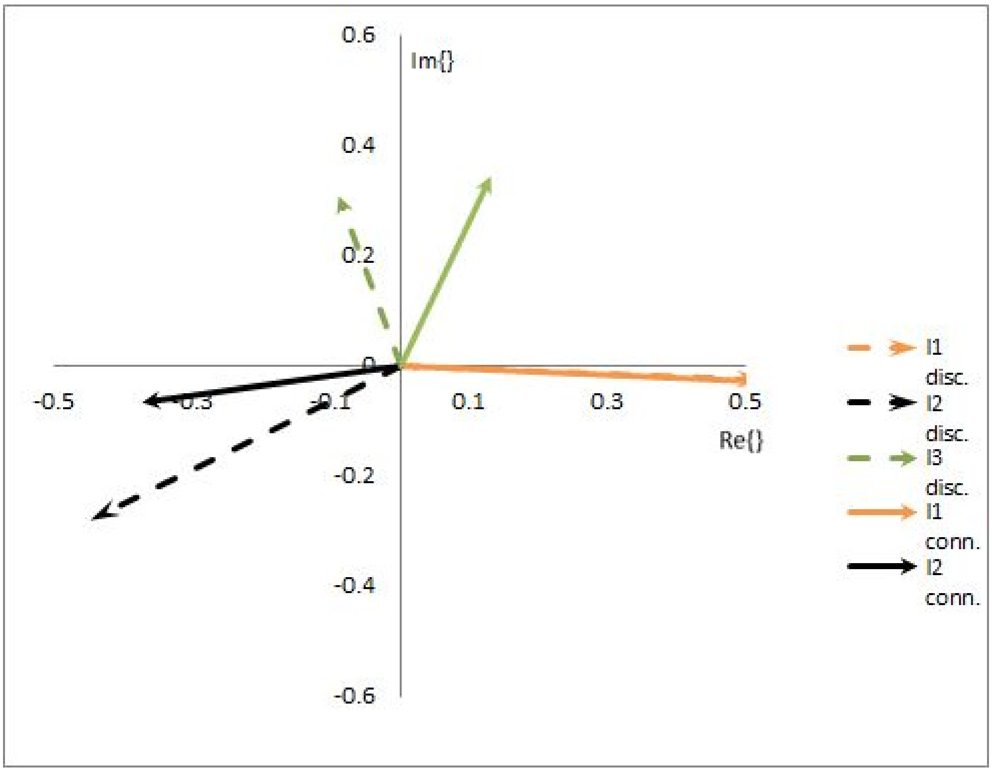

Figure 5.8: Task 2A Step 4-5 Shorted L, Neutrals Connection V Comparison

- **Based on your diagram, how does the unbalanced load affect the phase voltages when the neutral point on the load is not connected to the source neutral?**

  The unbalanced load with the neutral point on the load disconnected to the source neutral results in unstable phase voltage, causing the phase to change in ways that may be difficult to predict.

- **What is the effect of connecting the neutral points in Step 5?**

  By connecting the neutral points in step 5, the wye point returns to 0V due to the neutral wire, and carries out of balance current back to the supply.

- **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**

  The currents will not be equal and will not be symmetrical like in a balance case. The phase currents are unequal to the line currents, and there is no need for a neutral wire.

2.5D 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**

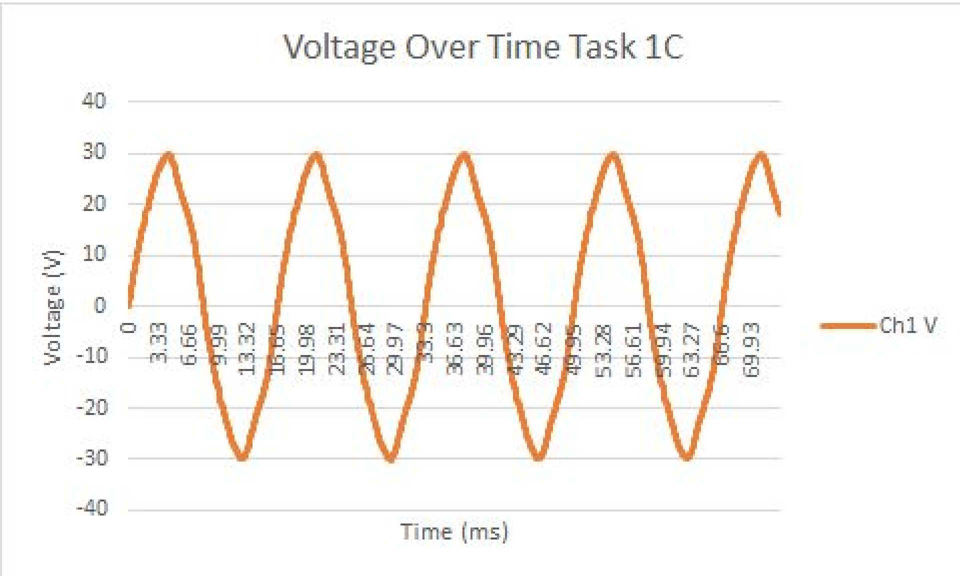

Figure 5.9: Task IC Voltage Over Time

- **How close is this waveform to an ideal sinusoid?**

  The shape of the voltage from the first channel follows the shape of a sine waveform. The top and bottom peaks reach roughly the same magnitude.

- **Using MATLAB FFT, calculate the harmonic content and 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.**

Harmonic Amplitudes vs Frequency

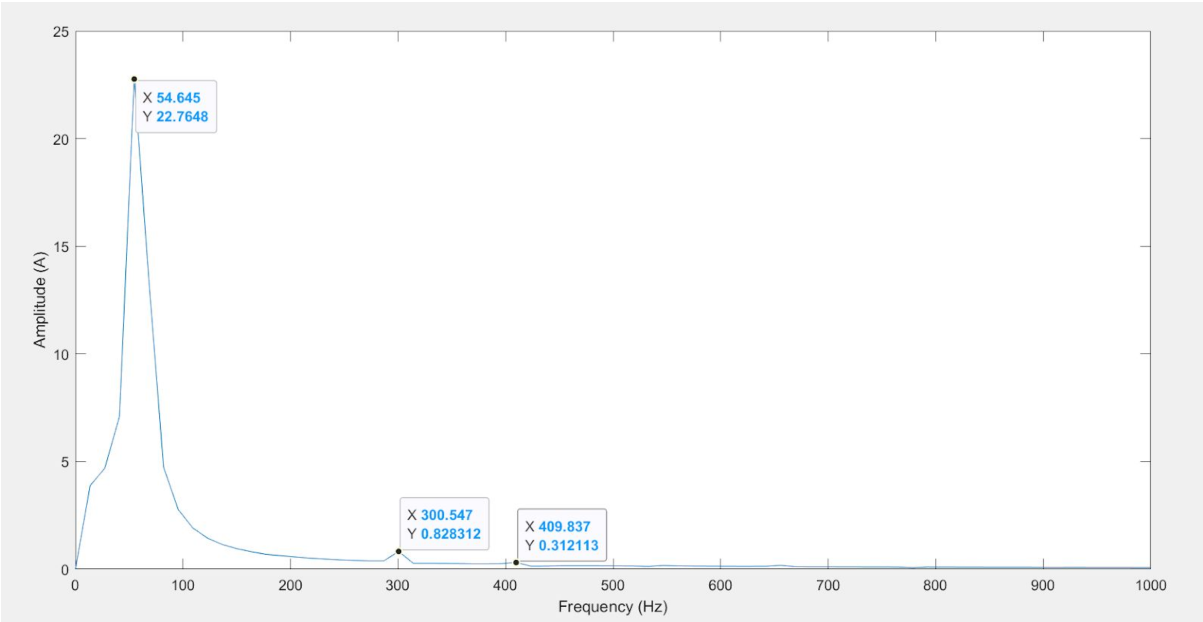

Figure 5.10: Harmonic Amplitudes vs Frequency

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

  Harmonics in AC systems are caused by non-linear loads, such as a rectifier. Non-linear loads can draw a current that is not necessarily sinusoidal. This creates a situation in which the current is not proportional to the voltage

2.5E Task 5 E: Single-Phase AC-DC Rectifiers

- **Using the measured/recorded current from Task 3A, first plot the recorded current waveform**

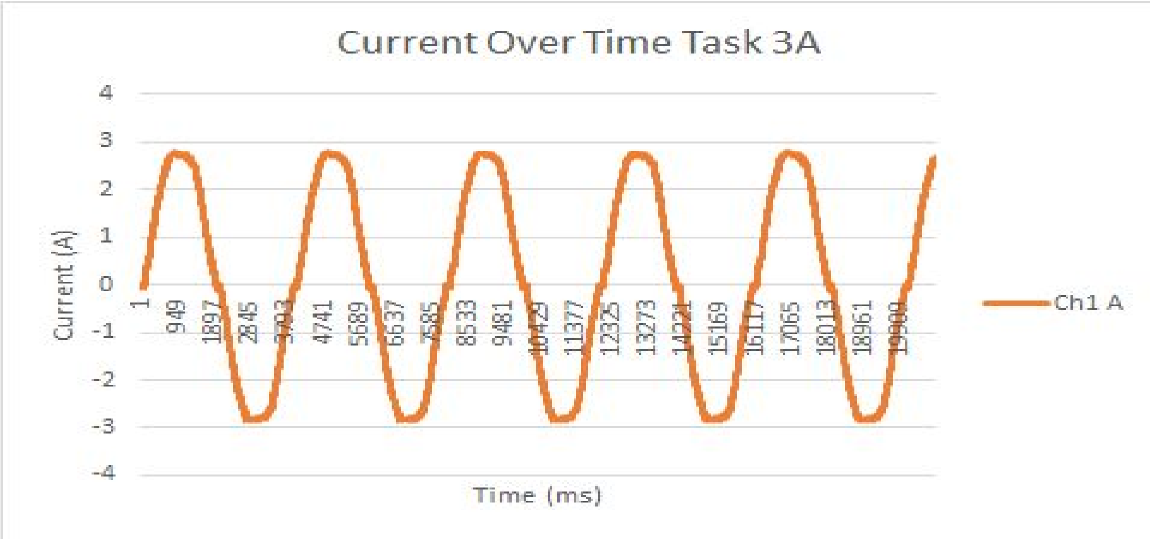

Figure 5.11: Task 3A Current Over Time

- **How close is this waveform to an ideal sinusoid?**

The shape of the current from the first channel follows the shape of a sine waveform. The top and bottom peaks reach roughly the same magnitude.

- **Using MATLAB FFT, calculate the harmonic content and plot this content where the harmonic amplitudes are either in Amps or normalized with respect to the fundamental component, same as in Task 5D**

Harmonic Amplitudes vs Frequency

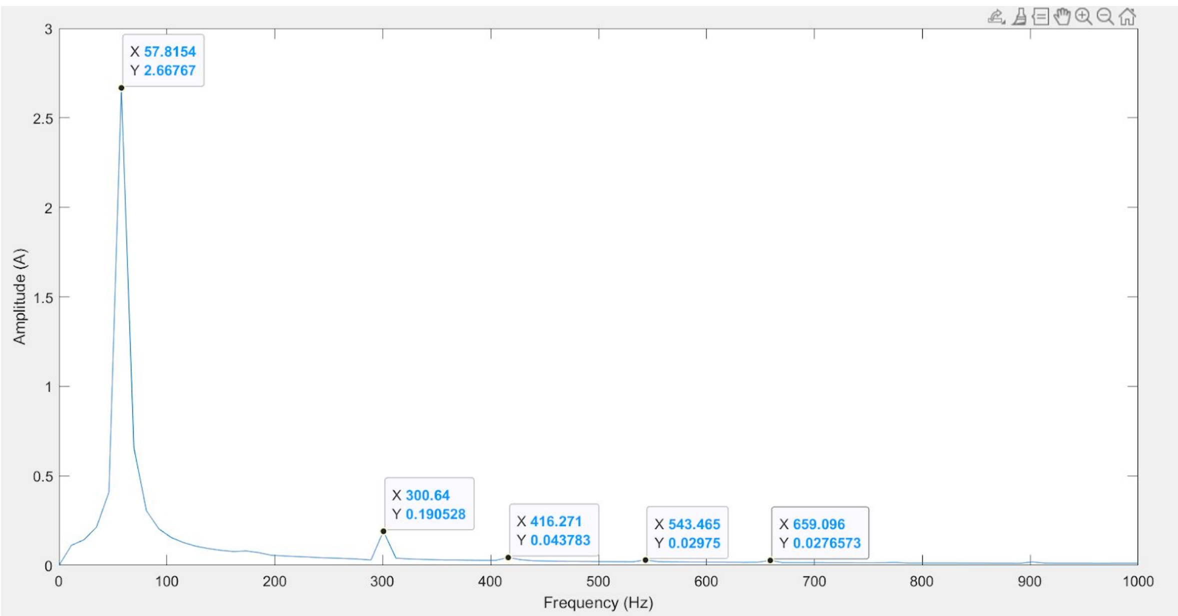

Figure 5.12:Harmonic Amplitudes vs Frequency

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

  The result of the same loads on the AC Mains should be similar to what is seen with the single-phase rectifier since they share the same principles.

2.5F 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.**

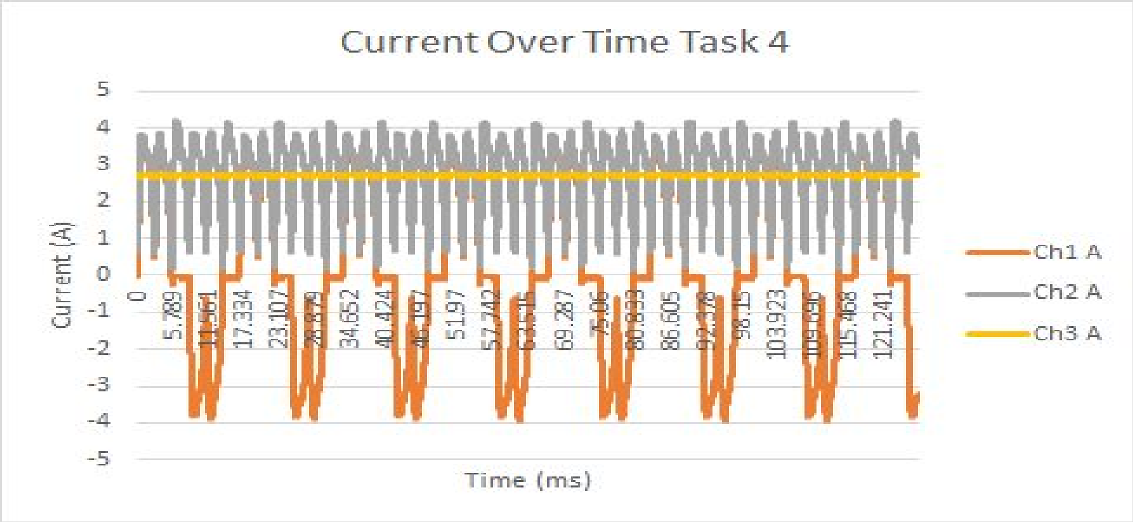

Figure 5.13: Task 4 Current Over Time

- **Explain the difference between I2 and I3**

  Both I2 and I3 are distorted. I2 has only positive values where I3 also has negative values. I2 is like taking the magnitude of I3.

- **Using MATLAB FFT, calculate the harmonic content of the phase current I1**

Harmonic Amplitudes vs Frequency

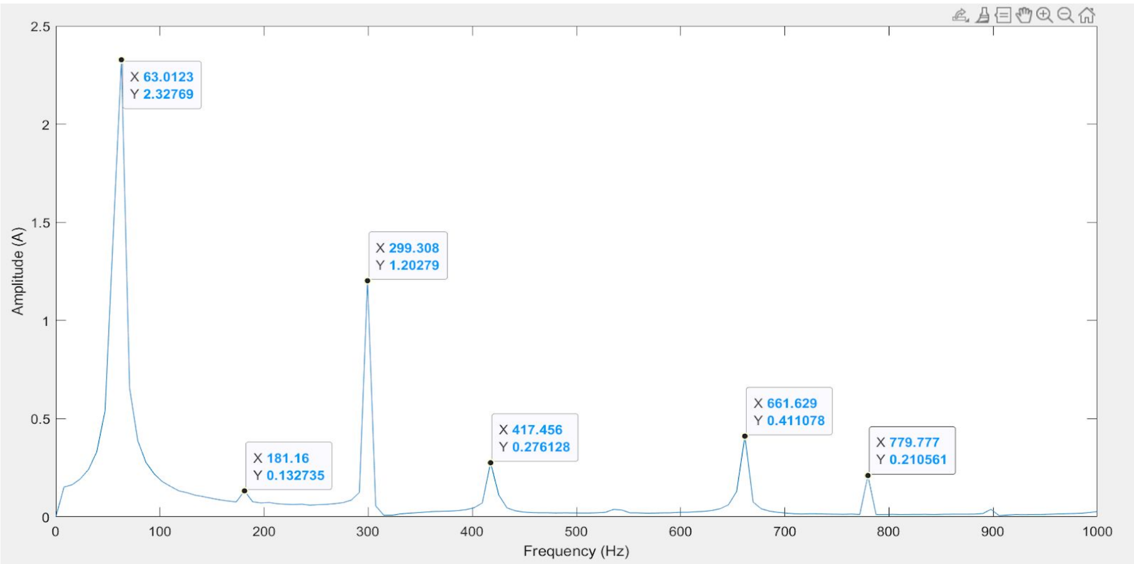

Figure 5.14: Harmonic Amplitudes vs Frequency

- **How does the waveform of the phase current I1 in Task 4 is different from current I1 in Task 3A?**

  Current I1 in Task 4 has more distortion than current I1 in Task 3A which makes the waveform for current I1 in Task 3A smoother than the one in Task 4. Both currents are measured with a capacitor filter, the difference between two tasks is that one task is single-phase where the other task is three-phase. Three phase circuits have more distortion.

3. Conclusion

This lab explored the basic properties of single phase and 3-phase RLC circuits, series and parallel connection of components, as well as ideal and non-ideal electrical components. Using recorded voltage and current data and measurements, the relationship between voltage and current phase differences, and electrical power was observed as phasor representations and waveforms. Phasor representation from the measured currents and voltages of a three phase RLC circuit was established to visualize the behaviours of AC circuit components and their effects on current and voltage. The meaning of instantaneous, real and reactive power was defined and plotted in order to observe their relationships. Furthermore, single-phase and three-phase AC-DC rectifier harmonic contents were calculated, plotted, and analysed to investigate the cause of harmonics in AC systems and this Lab.

Appendix A: MATLAB FFT Script

```
d = load('../../Task4B3.txt');

t = d(:,1)*1E-3;    % ms
c = d(:,6);     % current
L = length(t);
Ts = mean(diff(t));     % sampling interval (s)
Fs = 1/Ts;          % sampling freq
vc = c - mean(c);   % sub 0hz component

% Fourier Transform
Y = fft(vc);
P2 = abs(Y/L);
P1 = P2(1:L/2+1);
P1(2:end-1) = 2*P1(2:end-1);
f = Fs*(0:(L/2))/L;
plot(f,P1)
xlim([0 1000])
xlabel('Frequency (Hz)')
ylabel('Amplitude (A)')
```