MXET 375
Applied Dynamic Systems

Multidisciplinary Engineering Technology
COLLEGE OF ENGINEERING

LABORATORY # 4
RLC Circuit

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Introduction

The purpose of Lab 4 is to expand an individual's knowledge on how to model different configurations of an RLC (Resistor, Inductor, Capacitor) circuit system using the Simscape and Simscape Electrical libraries in Simulink and MATLAB. The objectives include gaining a general functionality understanding of basic circuit elements such as a resistor, power source, capacitor, and inductor, learning to create block diagram models using different Simulink libraries, and appropriately configuring simulation values to produce realistic behavior that can be observed and analyzed. Task 1 focuses on creating and modeling RLC Circuit 1 which represents a series configuration of an RLC circuit. Task 2 focuses on creating and modeling RLC Circuit 2 which represents a series with parallel resistor configuration of an RLC circuit. Task 3 focuses on creating and modeling RLC Circuit 3 which represents a parallel configuration of an RLC circuit. At the end of the lab not only should the individual have a better understanding of using basic Simulink electrical circuit library elements to accurately create and model electrical systems but also creating, plotting, configuring, and formatting configurations of RLC circuit system models, and their results, using Simulink, Simscape, Simscape Electrical, and MATLAB.

Procedure & Lab Results

This lab has three tasks total. Each task includes a detailed description of the setup, procedure, results, relevant figures, and discussion focusing on developing a better understanding and interpretation of what the results mean and how they were derived. Each of these tasks only has one part. Each part will represent a specific RLC circuit model configuration. The three RLC configurations can be seen in Figure 1.
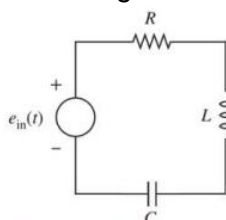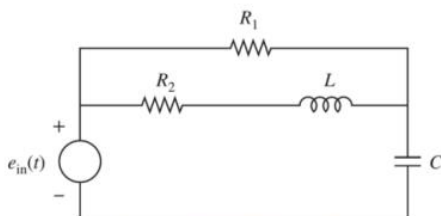

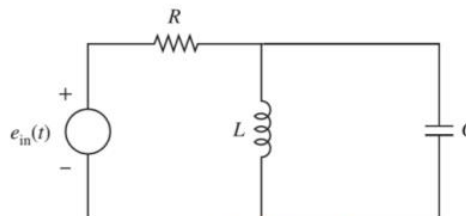*Figure 1: RLC Circuit 1*

Figure 2: RLC Circuit 2

Figure 3: RLC Circuit 3

Figure 1: RLC Circuit Configurations [1]

Each of the configurations include one AC voltage source and share consistent system parameter values across all configurations. The system parameters of these RLC Circuits include having an AC Voltage Peak Amplitude of 10 V, an AC Voltage Frequency of 1 kHz, Resistors (R, R1, R2) of 1 kOhm, an Inductor (L) of 100 mH, and a Capacitor (C) of 100 nF.

Task 1

With the understanding of how each task focuses on one of the three configurations shown in Figure 1 this task focuses on the creation and analyzation of configuration 1: RLC Circuit 1. The purpose of this task is to expand the understanding of creating, modeling, simulating, and analyzing basic electrical systems. This task provided the assignment of creating a block diagram of a RLC circuit system in a series configuration using common control system elements, the Simscape Electrical Library, and the Simscape Library. This system is made up of four voltage sensors, a current sensor, an inductor, a capacitor, a resistor, an electrical reference, an AC voltage source, five PS-simulink converter blocks, a solver configuration block, a bus creator, and a scope block. The current sensor will be used to measure the circuit's current in series while the voltage sensors will be used to measure voltage in parallel across each of the components. The provided lab manual for this lab walks through the exact setup, configuration, and procedure for creating this block diagram. The procedure for this began with importing all the required blocks and setting them up in the correct setup configuration. This is done in the same manner in which the original circuit schematic is drawn. The setup configuration of the required block diagram to produce the correct plots, with all block names, and the annotated connection line names, can be seen in Figure 2.
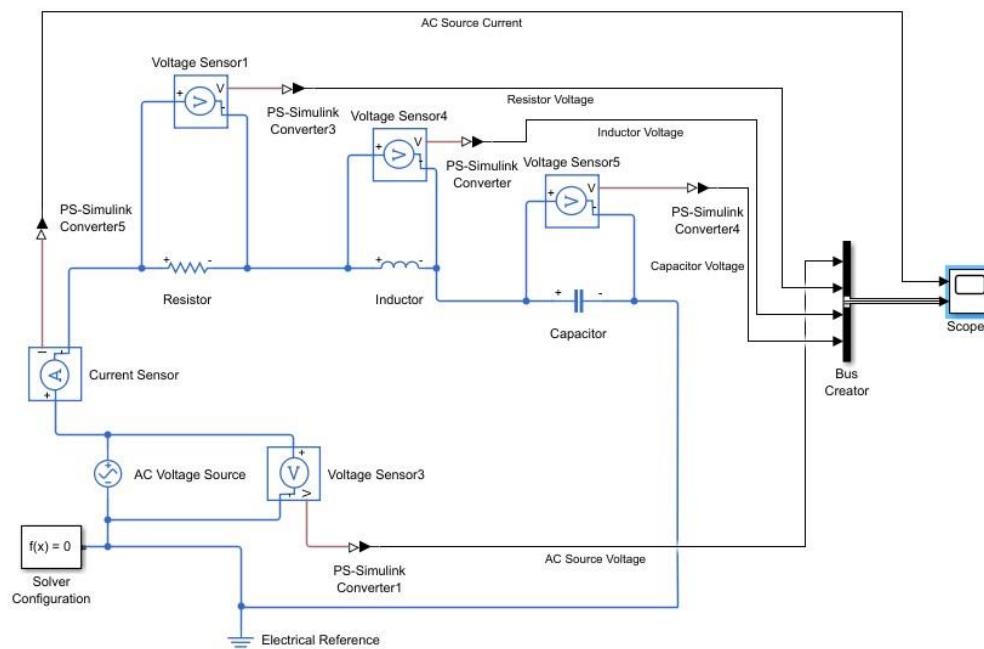

Figure 2: RLC Circuit 1 Series Complete Block Diagram

With the setup complete the next step was to configure each block with the appropriate values. In the case of this problem that is done by setting the AC voltage source (Peak amplitude) to 10 V, AC voltage source (Frequency) to 1 kHz, Resistor (R, R1, R2) (Resistance) to 1 kOhm, Inductor (L) (Inductance) to 100 mH, and Capacitor (C) (Capacitance) to 100 nF. Lastly, in the configuration parameters window of Simulink the stop time must be set to 3E-3 seconds and the solver must be changed to "ode23t (mod.stiff/Trapesoidal)". Once that is

complete the final step is to run the system and format the result to the specified requirements described in Lab 1 with a few changes. These changes include configuring the scope block to receive two inputs and show two separate displays, scaling the axes, and configuring all the labels (Title, labels, legends, etc.) to appropriately describe the plots. This result can be seen in Figure 3.
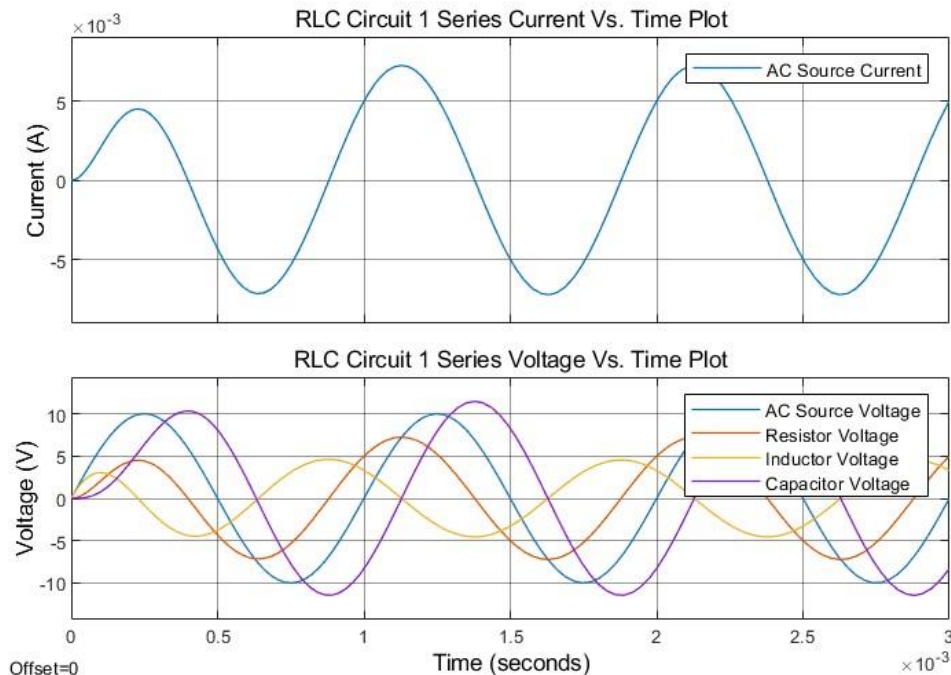

Figure 3: RLC Circuit 1 Series Current and Voltage Vs. Time Simulation Plot

The simulation of the RLC series circuit shows that the current follows a sinusoidal pattern, with its phase in alignment with the voltage across the resistor, as expected in such a configuration. The inductor voltage leads the current, while the capacitor voltage lags behind by approximately 90 degrees, demonstrating the characteristic phase shifts due to energy storage in the inductor and capacitor. The resistor's voltage remains in phase with the current, consistent with Ohm's law. These phase relationships and the magnitudes of the voltages across each component align with the expected behavior of an RLC circuit under AC excitation, reflecting the influence of inductive and capacitive reactance on the circuit's dynamic response. When comparing the relationship between the current and the capacitor's voltage specifically it can be concluded, based on a visual inspection of the graph, that the current leads the capacitor's voltage by around a quarter cycle (90 degrees). This means that the current reaches its maximum (or crosses zero) before the capacitor's voltage does. This is expected behavior for an RLC series circuit because the current leads the capacitor's voltage due to the nature of capacitor charging and discharging.

Task 2

With the understanding of how each task focuses on one of the three configurations shown in Figure 1, and with the completion of task 1 which focused on the creation and analyzation of configuration 1, this task focuses on the creation and analyzation of configuration

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2: RLC Circuit 2. The purpose of this task is the same as task 1, which is to expand the understanding of creating, modeling, simulating, and analyzing basic electrical systems. This task provided the assignment of creating a block diagram of a RLC circuit system in a series with parallel resistor configuration using common control system elements, the Simscape Electrical Library, and the Simscape Library. This system is made up of three voltage sensors, a current sensor, an inductor, a capacitor, two resistors, an electrical reference, an AC voltage source, four PS-simulink converter blocks, a solver configuration block, a bus creator, and a scope block. The current sensor will be used to measure the circuit's current in series while the voltage sensors will be used to measure voltage in parallel across each of the components. The provided lab manual for this lab walks through the exact setup, configuration, and procedure for creating this block diagram. The procedure for this began with importing all the required blocks and setting them up in the correct setup configuration. This is done in the same manner in which the original circuit schematic is drawn. The setup configuration of the required block diagram to produce the correct plots, with all block names, and the annotated connection line names, can be seen in Figure 4.
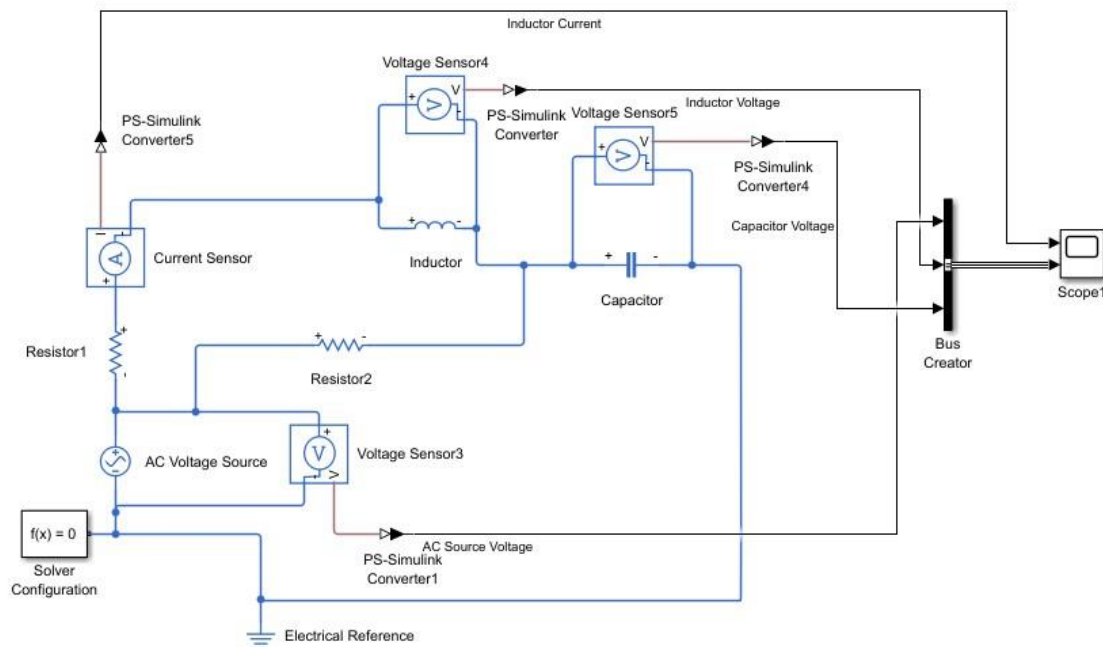

Figure 4: RLC Circuit 2 Series With Parallel Resistor Complete Block Diagram

With the setup complete the next step was to configure each block with the appropriate values. In the case of this problem that is done by setting the AC voltage source (Peak amplitude) to 10 V, AC voltage source (Frequency) to 1 kHz, Resistor (R, R1, R2) (Resistance) to 1 kOhm, Inductor (L) (Inductance) to 100 mH, and Capacitor (C) (Capacitance) to 100 nF. Lastly, in the configuration parameters window of Simulink the stop time must be set to 3E-3 seconds and the solver must be changed to "ode23t (mod.stiff/Trapesoidal)". Once that is complete the final step is to run the system and format the result to the specified requirements described in Lab 1 with a few changes. These changes include configuring the scope block to receive two inputs and show two separate displays, scaling the axes, and configuring all the

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labels (Title, labels, legends, etc.) to appropriately describe the plots. This result can be seen in Figure 5.
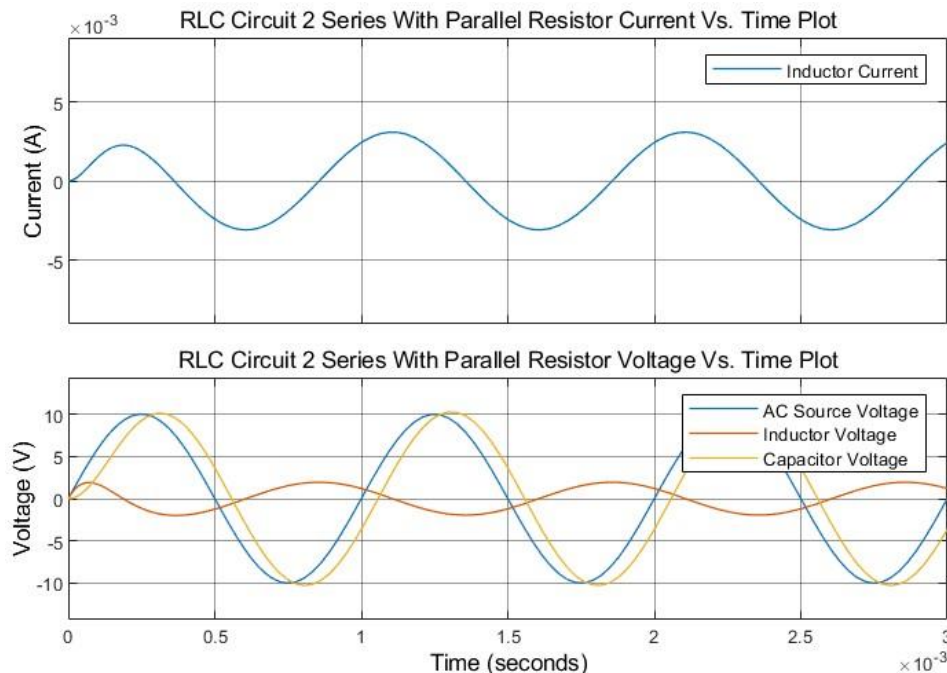

Figure 5: RLC Circuit 2 Series With Parallel Resistor Current and Voltage Vs. Time Simulation Plot

The simulation results of the RLC circuit with a series configuration and parallel resistor highlight the phase relationships between the components. The inductor voltage leads the current by 90 degrees, a typical behavior due to the inductive reactance. The capacitor voltage is nearly out of phase with the inductor voltage, indicating the opposing effects of the inductor and capacitor. The sinusoidal waveforms of both current and voltage demonstrate continuous energy exchange between the inductor and capacitor, while the resistors help dampen the oscillations. These results provide a clear visualization of the dynamic interactions between the circuit elements. When comparing the relationship between the current and the inductor's voltage specifically it can be concluded, based on a visual inspection of the graph, that the inductor's voltage leads the current by around 90 degrees. This means that the inductor's voltage reaches its maximum (or crosses zero) before the current does. This is expected behavior for an RLC series circuit because the voltage across an inductor is proportional to the rate of change of current causing the leading relationship.

Task 3

With the understanding of how each task focuses on one of the three configurations shown in Figure 1, and with the completion of tasks 1 and 2 which focused on the creation and analyzation of configuration 1 and 2 respectively, this task focuses on the creation and analyzation of configuration 3: RLC Circuit 3. The purpose of this task is the same as task 1, which is to expand the understanding of creating, modeling, simulating, and analyzing basic electrical systems. This task provided the assignment of creating a block diagram of a RLC circuit system in a parallel configuration using common control system elements, the Simscape

Electrical Library, and the Simscape Library. The difference between this task and the previous tasks is that the provided lab manual for this lab does not walk through the exact setup, configuration, and procedure for creating this block diagram. This requires the individual to, based upon the understanding of the creation of the previous two block diagrams, create a block diagram system to accurately model RLC Circuit 3. Additionally, this block diagram must capture certain voltage and current values for the circuit and its components. These values include the voltage across the AC voltage source, voltage across the inductor, voltage across the capacitor, and current through the capacitor. This can be done similarly to the previous systems where the current sensor will be used to measure the circuit's current in series while the voltage sensors will be used to measure voltage in parallel across each of the components. Knowing all of this the final system can be created using the following: three voltage sensors, a current sensor, an inductor, a capacitor, a resistor, an electrical reference, an AC voltage source, four PS-simulink converter blocks, a solver configuration block, a bus creator, and a scope block. The procedure for this began with importing all the required blocks and setting them up in the correct setup configuration. This is done in the same manner in which the original circuit schematic is drawn. The setup configuration of the required block diagram to produce the correct plots, with all block names, and the annotated connection line names, can be seen in Figure 6.
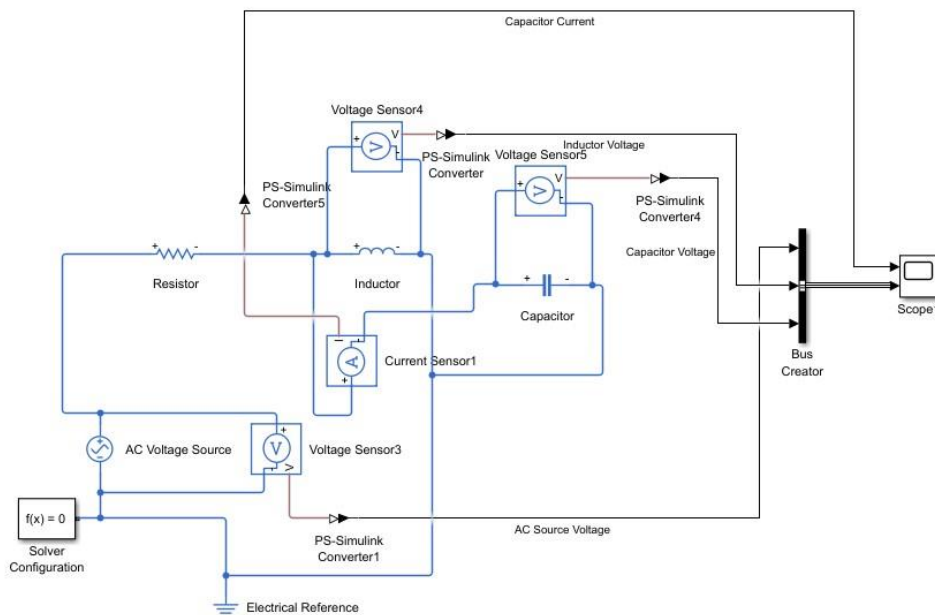
Figure 6: RLC Circuit 3 Parallel Complete Block Diagram

With the setup complete the next step was to configure each block with the appropriate values. In the case of this problem that is done by setting the AC voltage source (Peak amplitude) to 10 V, AC voltage source (Frequency) to 1 kHz, Resistor (R, R1, R2) (Resistance) to 1 kOhm, Inductor (L) (Inductance) to 100 mH, and Capacitor (C) (Capacitance) to 100 nF. Lastly, in the configuration parameters window of Simulink the stop time must be set to 3E-3 seconds and the solver must be changed to "ode23t (mod.stiff/Trapesoidal)". Once that is complete the final step is to run the system and format the result to the specified requirements

described in Lab 1 with a few changes. These changes include configuring the scope block to receive two inputs and show two separate displays, scaling the axes, and configuring all the labels (Title, labels, legends, etc.) to appropriately describe the plots. This result can be seen in Figure 7.
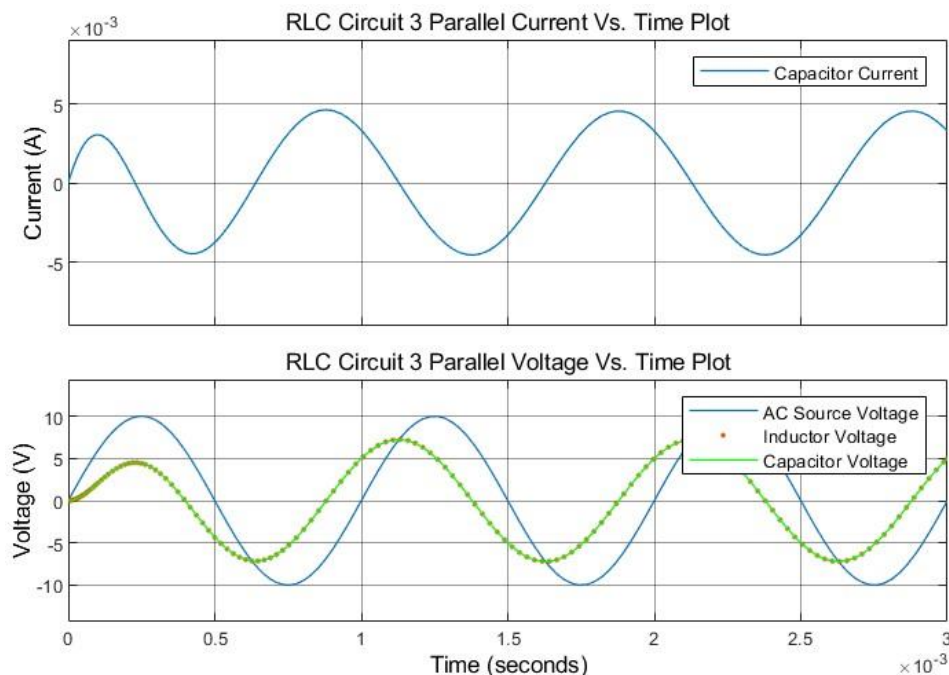

Figure 7: RLC Circuit 3 Parallel Current and Voltage Vs. Time Simulation Plot

The simulation results for the parallel RLC circuit reveal that the voltages across the inductor and capacitor are identical in both magnitude and phase, indicating resonance, where the inductive reactance and capacitive reactance are equal and cancel each other out. The capacitor current exhibits a sinusoidal waveform, characteristic of its response to an AC input, with peaks occurring as the voltage crosses zero. The AC source voltage shows a noticeable phase difference relative to the voltages across the reactive components, illustrating the typical phase relationships in RLC circuits. The plots effectively highlight the resonance condition and the expected current-voltage behavior within the system. When comparing the relationship between the inductor's voltage and capacitor's voltage specifically it can be concluded, based on a visual inspection of the graph, that they do not differ. The inductor's voltage and capacitor's voltage remain the exact same throughout the simulation. This occurs because of the configuration of the RLC circuit being in parallel which causes resonance to occur. Resonance occurs when the inductive reactance and capacitive reactance are equal. Resonance causes the inductor and capacitor voltages to be equal in magnitude and phase, which is why their plots overlap.

Post-Lab Questions

To answer the questions below pertaining to the signal's values. You will need to view the models' scope output and view the "curser measurements" and or the "signal statistics" for the particular trace. While in the scope, you can open the two tools by clicking on "Tools"

then "Measurements". You can also access them by clicking on the small ruler icon. It is the far-right icon at the top menu bar within the scope. Play around with these tools to get a sense on how they work.

From task 1:
1. What is the peak-to-peak voltage across the resistor to 3 decimal places?

       The peak to peak voltage across the resistor to 3 decimal places is 14.461 V.

2. What is the relationship (leading or lagging) between the current and the capacitor's voltage? Is this behavior expected?

       Based on a visual inspection of the graph it can be concluded that the current leads the capacitor's voltage by around a quarter cycle (90 degrees). This means that the current reaches its maximum (or crosses zero) before the capacitor's voltage does. This is expected behavior for an RLC series circuit because the current leads the capacitor's voltage due to the nature of capacitor charging and discharging.

From task 2:
3. What is the max voltage across the inductor to 3 decimal places?

       The max voltage across the inductor to 3 decimal places is 1.945 V.

4. What is the relationship (leading or lagging) between the current and the inductor's voltage? Is this behavior expected?

       Based on a visual inspection of the graph it can be concluded that the inductor's voltage leads the current by around 90 degrees. This means that the inductor's voltage reaches its maximum (or crosses zero) before the current does. This is expected behavior for an RLC series circuit because the voltage across an inductor is proportional to the rate of change of current causing the leading relationship.

From task 3:
5. What is the RMS voltage across the capacitor to 3 decimal places?

       The RMS voltage across the capacitor to 3 decimal places is 4.386 V.

6. How does the plot for the inductor's voltage and capacitor's voltage differ? Why?

       They do not differ. The inductor's voltage and capacitor's voltage remain the exact same throughout the simulation. This occurs because of the configuration of the RLC circuit being in parallel which causes resonance to occur. Resonance occurs when the inductive reactance and capacitive reactance are equal. Resonance causes the inductor and capacitor voltages to be equal in magnitude and phase, which is why their plots overlap.

Conclusion

In conclusion, Lab 4 provided a comprehensive understanding of modeling RLC circuits using Simulink, Simscape, and Simscape Electrical libraries in MATLAB. Through the creation and simulation of three different RLC circuit configurations, series, series with a parallel resistor, and parallel, key insights into the behavior of circuit components such as resistors, inductors, and capacitors were gained. The lab tasks focused on designing accurate block diagram models, configuring simulation parameters, and analyzing current and voltage responses over time. In Task 1, the RLC series circuit showed expected sinusoidal current behavior, with characteristic phase shifts between the current, inductor, and capacitor voltages. Task 2, which included a parallel resistor in the circuit, highlighted the opposing effects of inductive and capacitive reactance. Lastly, Task 3 demonstrated resonance conditions in the parallel RLC circuit, where the inductor and capacitor voltages were equal in magnitude and phase, confirming resonance behavior. Overall, the lab provided valuable practical experience in simulating electrical systems and interpreting their dynamic responses, reinforcing theoretical concepts of RLC circuit behavior under AC excitation.

References

[1] Author not listed, *Texas A&M University MXET375 - Lab 04 - RLC Circuit*. College Station, TX, USA: Date not listed.
[2] Rex K., *MXET375 - Kyle Rex - Lab Report 3*. College Station, TX, USA: 09/26/2024.