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Lab 2: Thevenin's Theorem, LabView, and AC Circuits

Introduction

The purpose of this lab is broken up into three parts: to understand Thevenin's Theorem, learn how to use LabView, and characterize the behavior of capacitors and inductors in AC circuits. Thevenin's Theorem allows for a simplification of a circuit with multiple resistors and voltage sources to a Thevenin equivalent circuit, which consists of one equivalent voltage source and an equivalent resistor in series (Gannett, Lab handout, 2019). Figure 1 demonstrates the circuit constructed and Figure 2 shows the simplification of the circuit with the use of Thevenin's Theorem. LabView is a programming tool that enables control by a user when analyzing circuits. As opposed to DC power sources, AC power sources produce an oscillating voltage.

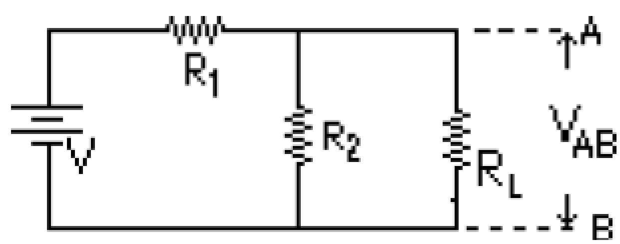


Figure 1. Circuit schematic for Thevenin's Theorem procedure (Gannett, Lab handout, 2019).

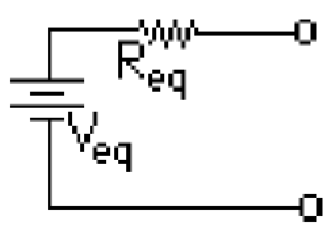
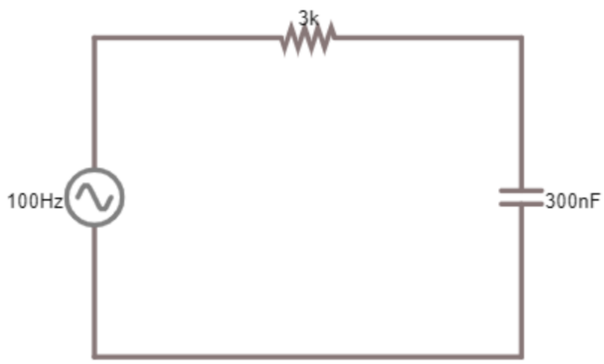


Figure 2. Thevenin equivalent circuit (Gannett, Lab handout, 2019).



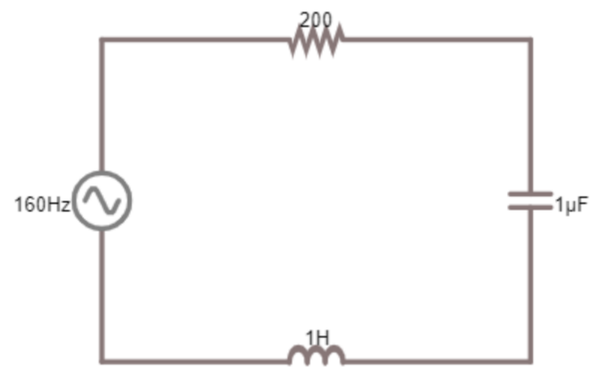


Figure 3. RC and RLC circuits used in parts 6 and 7 of the lab, respectively.

(Circuit diagrams courtesy of Paul Falstad's circuit simulator)

Methodology

Determining values of components for the Thevenin Theorem procedure involved theoretical hand calculations and actual measurements made with a multimeter. Table 1 includes the measured and theoretical values of the circuit components shown in Figure 1.

Circuit Component	Theoretical Value	Measured Value	Units
R1	4.7	4.631	kΩ
R2	2.2	2.14	kΩ
RL	2.2	2.21	kΩ
V	9	9	V

Table 1. Component values from Thevenin portion of the lab procedure.

Two quantities are required to characterize the Thevenin equivalent circuit: the equivalent voltage, V_{eq}, and the equivalent resistance, R_{eq}. First, the equivalent voltage is found by removing the load resistor, R_L, from the circuit diagram and calculating the resulting voltage between points A and B on Figure 1. Next, the equivalent resistance is found by returning the load resistor to the circuit, replacing the voltage source with a wire, and calculating the resistance between points A and B. Finally, the Thevenin equivalent circuit is constructed by placing a resistor of value R_{eq} in series with a voltage source of value V_{eq}.

As an alternative to the theoretical calculation described above, the Thevenin equivalent resistance can be determined experimentally through the following procedure. First, measure the equivalent voltage by removing the variable load resistor R_L from the circuit and attaching the leads of a voltmeter or oscilloscope in its place. Once the equivalent voltage has been determined, return the load resistor to the circuit and adjust its value until the voltage across it is half of the equivalent voltage. When this condition is met, the value of the load resistor will equal the equivalent resistance. This procedure takes advantage of the voltage divider relation:

$$V_L = \frac{R_L}{R_L + R_{eq}} V_{eq}$$

Adjusting the load resistance until $V_L = \frac{1}{2} V_{eq}$ forces the resistance ratio on the right hand side to equal one-half as well. Inspection reveals that this condition is satisfied only when $R_L = R_{eq}$.

The LabView portion of the procedure centered around the maximum power transfer theorem, which describes the condition for maximum power delivery to the load. This condition can be found by differentiating the load power with respect to the load resistance R_L and finding its root:

$$\frac{dP_L}{dR_L} = \frac{d}{dR_L} I^2 R = \frac{d}{dR_L} \frac{V_{eq}^2 R_L}{(R_{eq} + R_L)^2} = 0$$

which yields the solution $R_L = R_{eq}$. Qualitatively, this condition represents a balancing point between the current and the voltage drop across the load. If R_L is made greater than R_{eq}, then it will consume a larger portion of the total power; however, it will also limit the current in such a way that its power experiences a net decrease. Conversely, if R_L is made less than R_{eq}, then a larger current will be able to flow; however, it will dissipate a smaller fraction of the total power, again causing a net decrease in the power to the load.

During the LabView procedure, the NI-DAQmx DAQ Assistant was used to measure voltages from the components in the circuit by use of the channels. From the information given by the channels, mathematical functions were inserted on LabView to find unknown values of the circuit. The resistance on the decade box was manipulated to find which resistance value maximized the power delivered to it by running LabView to compare power values.

The AC circuit procedure used both hand calculation and LabView to determine voltages across components of the circuit. When hand calculating voltages, the voltage divider rule was implemented. Because we were working with alternating current, values were calculated using complex numbers for impedances. The differences in phase angle for the capacitor, resistor, and inductor impedances caused phase shifts in the voltages across each component. These phase differences were characterized quantitatively through theoretical calculations and qualitatively by voltage plots produced in LabView.

Discussion

Our calculation for the Thevenin equivalent voltage was 2.844 V, while the equivalent resistance was 1.464 kΩ. After setting our load resistance equal to the theoretical equivalent resistance, we measured a voltage of 1.428 V across the load. This is nearly equal to half of the equivalent voltage, with only a 0.4% error from the predicted value of 1.422 V. In addition, maximum power transfer to the load occurred at the same value of the load resistance. Both of these results are in agreement with our discussion in the Methodology section.

For the RC circuit, our measured value for the voltage across the capacitor of 0.880 V peak-to-peak very nearly agreed with our predicted value of 0.870 V. Our underestimate suggests that either the capacitor had a higher impedance or the resistor had a lower impedance than expected; however, with only a 1.1% error, our results still agree very closely with our calculation. The voltage across the capacitor in this arrangement is out of phase by -29.5° relative to the resistor. Doubling the resistance to 6 kΩ results in a phase difference of -48.5°, and the peak-to-peak voltage changes to 0.662 V.

For the RLC circuit, our calculation of the capacitor voltage gave a peak-to-peak voltage of 4.967 V and a phase of -92.95°. This value is surprising, because it is nearly five times as large as the input voltage; in DC circuitry, the voltage drop across a component is always less than or equal to the supply voltage. Unlike our results for the RC circuit, our measured voltage in the RLC circuit was inconsistent with our calculation. With a value of 3.36 V, our measurement had a 32.4% error based on our theoretical prediction. There is some uncertainty associated with the capacitance and inductance delivered by the decade boxes, but it seems unlikely that it would result in such a large error.

However, our predictions for the phase relationships were very accurate. Theory predicts that the inductor voltage leads the resistor voltage by 90°, while the resistor leads the capacitor by 90°. Although we were not able to quantify the phase differences in our measurements, the attached graph of our resistor, capacitor, and inductor voltage measurements strongly agrees with our prediction.

Conclusion

Breaking down a complicated circuit to the Thevenin Equivalent allows for a simpler analysis of calculating resistance and voltage across the circuit. LabView is a very useful tool that enables user manipulation with a circuit connected and provides graphical results that can be analyzed to determine different relationships between different characteristics of the circuit such as current and voltage. When analyzing an AC circuit impedance, complex numbers are introduced into the analysis to provide direction.