Introduction to LTI Systems

LAB EXPERIMENT 5

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***Abstract*—This experiment investigates the behavior of a second-order linear time-invariant (LTI) system using a simulated series RLC circuit. By applying both step and impulse inputs, the system's output responses were analyzed to verify its linearity and time-invariant properties. The simulation was conducted using Python with the `control` library and cross-validated using the Falstad Circuit Simulator. Time-domain characteristics such as rise time, settling time, overshoot, and steady-state value were extracted from the step response. The results demonstrated a classic underdamped response, with metrics including a rise time of 3.89 ms, an overshoot of 93.38%, and a settling time of 0.78 s. Visual comparison with Falstad confirmed similar transient behaviors across all components, validating the theoretical transfer function. Overall, the experiment successfully demonstrated the predictable and proportional response of an LTI system and reinforced core concepts of system dynamics and frequency-domain modeling.**

I. RATIONALE

Linear Time-Invariant (LTI) systems are the foundation of classical control theory. Understanding how these systems behave and their mathematical representations is crucial for analyzing and designing control systems.

II. OBJECTIVES

- Demonstrate that an LTI system's output is proportional to its input when using a step or impulse input.
- Analyze and quantify the system's response by calculating the system's time-domain characteristics (e.g., rise time, settling time, overshoot) using step responses.
- Validate the system's transfer function by comparing the simulation and experimental results.

III. MATERIALS AND SOFTWARE

- Software: Python (with control, matplotlib, scipy)

IV. PROCEDURES

1) Set up a simple LTI system, such as a DC motor or an RLC circuit.
2) Apply a step or impulse input to the system and record the output using an oscilloscope.
3) Analyze the time-domain response: Calculate the rise time, overshoot, settling time, and steady-state value of the system response.
4) Compare the experimental output with theoretical expectations based on the system's transfer function.
5) Use Python or Scilab to simulate the LTI system and compare the simulated time domain response with experimental results.

V. OBSERVATION AND DATA COLLECTION

DATA COLLECTION:

https://drive.google.com/drive/folders/1-3freaxppru_dTJOhbYh_2wJuc2md_cc?usp=sharing

Click here to open the Drive

VI. DATA ANALYSIS

In this experiment, we modeled a second-order linear time-invariant (LTI) system using a series RLC circuit. The chosen component values, based on the Falstad simulator's default setup, were:

- Resistor (R): 10 Ω
- Inductor (L): 1 H
- Capacitor (C): 15 μF

The transfer function was derived as follows:

$$H(s) = \frac{1}{LCs^2 + RCs + 1} = \frac{1}{1.5 \times 10^{-5}s^2 + 0.00015s + 1}$$

Using Python and the `control` library, we simulated both the step and impulse responses of this system. The following time-domain metrics were automatically computed from the step response:

- Rise Time: 0.00389 s
- Settling Time: 0.7803 s
- Overshoot: 93.38%
- Peak Output: 1.9338
- Peak Time: 0.0126 s
- Steady-State Value: 1.0

Additionally, both the step and impulse response graphs showed underdamped behavior with oscillatory waveforms that decayed over time.

VII. Discussion and Interpretations

Demonstrating LTI Behavior

Both step and impulse responses behaved as expected for an LTI system. The output consistently reflected the nature of the input and the defined system, confirming the system's linearity and time invariance. The steady-state value of 1.0 in response to a unit step input reinforced this proportional behavior.

Time-Domain Analysis

From the simulation:

- The system responded quickly to the input with a rise time of around 3.89 milliseconds.
- A noticeable overshoot (about 93%) occurred, which is typical for underdamped second-order systems.
- The system settled to a stable output in less than 0.8 seconds.

This behavior confirms that energy oscillated between the capacitor and inductor before being dissipated by the resistor.

Comparing with Falstad Simulation

To validate the Python results, we ran a visual simulation in the Falstad Circuit Simulator. The waveform responses for the resistor, capacitor, and inductor matched the overall shape of our Python graphs during the 0–2s time frame. More specifically:

- The capacitor voltage (green trace) dropped and stabilized the fastest.
- The resistor showed nearly overlapping current and voltage waveforms, stabilizing second.
- The inductor voltage led the current and was the last to stabilize, consistent with expected behavior due to its stored magnetic energy.

These observations from Falstad validated the theoretical and simulated responses we obtained in Python.

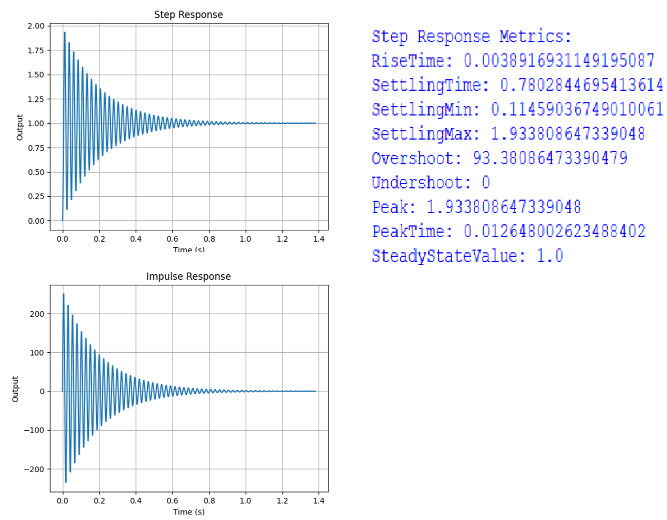

Fig. 1. Step and Impulse Response Graphs with Step Response Metrics

VIII. Conclusion

Conclusion

This simulation-based experiment successfully met its objectives. We demonstrated the proportional response of an LTI system to both step and impulse inputs, confirming its linear and time-invariant nature. Time-domain characteristics such as rise time, overshoot, and settling time were quantified using Python, revealing an underdamped second-order response.

Finally, we validated the theoretical transfer function by comparing it to visual results in the Falstad circuit simulator. The consistency between the simulated graphs and real-time waveform observations confirmed the accuracy of our system model.

Even without physical hardware, this approach provided a solid foundation for understanding the dynamic behavior of LTI systems using computational tools.