FIRST ORDER LTI SYSTEM TRANSIENT RESPONSE ANALYSIS

LAB EXPERIMENT 9

Harel Ko
BS Electronics Engineering, Samar State University (of Aff.)
Institute of Electronics Engineers of the Philippines (of Aff.)
Catbalogan City, Philippines
Harelko999@gmail.com

Luis Nacional
BS Electronics Engineering, Samar State University (of Aff.)
Institute of Electronics Engineers of the Philippines (of Aff.)
Catbalogan City, Philippines
Obeywes7@gmail.com

***Abstract*—This experiment investigates the transient response of a first-order Linear Time-Invariant (LTI) system using Python-based simulation, specifically modeling an RC (resistor-capacitor) charging circuit. Due to the unavailability of physical components, all procedures were carried out through numerical methods. The objective was to determine key time-domain characteristics of the system: time constant, rise time, settling time, and steady-state value, and to verify their theoretical relationships. A unit step input was applied, and the resulting output was plotted and analyzed. The results closely matched theoretical predictions, confirming that simulation provides a reliable approach for exploring system dynamics in the absence of hardware. The experiment reinforces fundamental control system concepts and demonstrates the practical value of time-domain analysis even through virtual means.**

I. RATIONALE

First-order systems are simple but fundamental in control theory. This experiment investigates the transient response of a first-order LTI system.

II. OBJECTIVES

- Calculate the time constant of a first-order system from its transient response.
- Measure the system's rise time, settling time, and steady-state value.
- Verify the relationship between the time constant and the system's transient behavior.type.

III. MATERIALS AND SOFTWARE

- Materials: RC circuit, Power Supply, Oscilloscope. (Simulated through Falstad.com/Circuit/)
- Software: Python (with matplotlib)

IV. PROCEDURES

1) Set up a first-order system, such as an RC circuit.
2) Apply a step input and observe the transient response on the oscilloscope.
3) Calculate the system's time constant and compare it with the time-domain response (e.g., rise time, settling time).
4) Verify the system's behavior by comparing experimental results with theoretical predictions

V. OBSERVATION AND DATA COLLECTION

DATA COLLECTION:

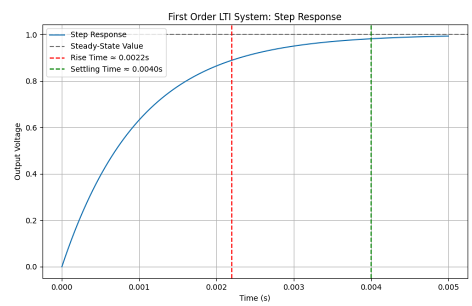

Fig. 1. Step Response and Pole-Zero Mao

https://drive.google.com/drive/folders/1ogdOKnEaOG8PHDG9FkZ1zDoivSC1YEUj

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VI. DATA ANALYSIS

The system modeled was an RC circuit with $R = 1\,\mathrm{k}\Omega$ and $C = 1\,\mu\mathrm{F}$, resulting in a time constant $\tau = RC = 0.001\,\mathrm{s}$. The transfer function of the system was represented as:

$$H(s) = \frac{1}{\tau s + 1}$$

A unit step input was applied, and the transient response was plotted over a time range of 0 to 5τ (0 to 0.005 s). From the simulation, the following characteristics were observed:

- **Time Constant** (τ): $0.001\,\mathrm{s}$
- **Rise Time** (10% to 90% response): approximately $2.2\tau = 0.0022\,\mathrm{s}$
- **Settling Time** (within 2% of final value): approximately $4\tau = 0.004\,\mathrm{s}$
- **Steady-State Value**: 1.0

The response graph demonstrated the typical exponential rise of a first-order system approaching its final value. Vertical reference lines were included in the plot to indicate estimated rise and settling times, and the horizontal dashed line denoted the steady-state value.

VII. DISCUSSION AND INTERPRETATIONS

The results of the simulation aligned closely with theoretical expectations for a first-order system. The time constant τ dictated the speed at which the system responded to the step input. Specifically, the rise time, defined as the interval required for the output to go from 10% to 90% of the steady-state value, was estimated using the empirical relation $t_r \approx 2.2\tau$, and this held true in the simulation.

Likewise, the settling time—an important metric indicating when the output stays within a small margin (usually 2%) of the final value—followed the expected rule of thumb $t_s \approx 4\tau$. The steady-state value approached 1.0, consistent with the unit step input and unity system gain. These consistent results reinforce the notion that the system's transient behavior is governed primarily by the time constant. Even without physical measurements from an oscilloscope, the simulation allowed for accurate analysis of the transient response. The close match between simulation and theory highlights the validity of using computational tools to study system dynamics, especially when resources are limited.

VIII. CONCLUSION

This experiment successfully met its objectives by using Python simulations to analyze the transient response of a first-order LTI system. Key parameters such as time constant, rise time, settling time, and steady-state value were identified and matched theoretical predictions closely. The results demonstrate the effectiveness of time-domain analysis in understanding the behavior of first-order systems. Moreover, the experience shows that simulation tools can serve as powerful alternatives to physical setups, enabling deeper conceptual learning when laboratory access is constrained. Through this experiment, the core principles of control system behavior were both visualized and validated.