Model-Based Design and Closed-Loop Control of an Electric Vehicle Powertrain

Md Helal Uddin
Electronic Engineering

December 14, 2025

Abstract

This project focuses on the development of a real-time capable plant model for a Battery Electric Vehicle (BEV) using MATLAB/Simulink. The system includes a physical model of the battery, DC motor, transmission, and longitudinal vehicle dynamics. A closed-loop PID control architecture was implemented to track dynamic drive cycles. The simulation results demonstrate the system's ability to accurately follow a reference speed profile under physical constraints such as aerodynamic drag and inertia.

Contents

1 Introduction

Hardware-in-the-Loop (HIL) and Model-Based Design (MBD) are industry standards for automotive development. This project aims to simulate a complete EV powertrain and design a feedback controller to regulate vehicle speed, satisfying requirements for dynamic response and stability.

2 System Modeling (The Plant)

The "Plant Model" represents the physical components of the vehicle. It is constructed using first-principles physics equations.

2.1 Battery and Motor

The energy source is modeled as an ideal DC voltage source. The electric motor is modeled using the fundamental DC motor equations:

$$V_{in} = I_a R_a + L_a \frac{dI_a}{dt} + K_e \omega \tag{1}$$

$$T_{motor} = K_t I_a \tag{2}$$

Where V_{in} is the input voltage, K_e is the Back-EMF constant, and K_t is the torque constant.

2.2 Transmission (Gearbox)

To increase torque at the wheels, a simple gear reduction is applied:

$$\omega_{wheel} = \frac{\omega_{motor}}{G}, \quad T_{wheel} = T_{motor} \times G \tag{3}$$

In this simulation, a gear ratio of $G = 10$ is used.

2.3 Vehicle Body Dynamics

The longitudinal motion of the vehicle is governed by Newton's Second Law ($F = ma$). The net force acting on the vehicle includes the traction force minus aerodynamic drag:

$$m\frac{dv}{dt} = F_{traction} - F_{drag} \tag{4}$$

$$F_{drag} = \frac{1}{2}\rho C_d A v^2 \tag{5}$$

This feedback loop (drag dependent on velocity squared) ensures realistic terminal velocity behavior.

3 Control System Design

To enable autonomous speed tracking, a "Driver" model was implemented using a PID controller.

3.1 Closed-Loop Architecture

The control system operates in a closed loop:

- **Input:** Target Velocity (from Drive Cycle).
- **Feedback:** Actual Velocity (from Vehicle Sensor).
- **Error Calculation:** $e(t) = v_{target} - v_{actual}$.
- **Controller Output:** Voltage command to the motor.

3.2 PID Tuning

A Proportional-Integral-Derivative (PID) controller was tuned to balance response time and overshoot.

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \tag{6}$$

Parameters used: $K_p = 50$, $K_i = 25$, $K_d = 0$. The Integral term ensures zero steady-state error during cruising.

4 Simulation Results

The system was validated using a custom "City Drive Cycle" created via the Simulink Signal Editor.

4.1 Test Scenario

The drive cycle consists of three phases:

1. **Acceleration:** 0 to 5 m/s.
2. **Cruising:** Constant speed at 5 m/s.
3. **Braking:** Deceleration to full stop.

4.2 Performance Analysis

The scope results confirm that the controller successfully adjusts the motor voltage to track the reference speed. The system exhibits initial overshoot due to vehicle inertia but settles quickly to the target speed, demonstrating stable closed-loop behavior suitable for HIL applications.

5 Conclusion

The project successfully implemented a complete electric powertrain model with closed-loop control. The simulation validates the interaction between electrical, mechanical, and control domains, fulfilling the requirements for a basic automotive simulation model (ASM).