Model-Based Design
of an Electric Vehicle Powertrain

Md Helal Uddin

Electronic Engineering

12.12.2025

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, electric motor, transmission, and longitudinal vehicle dynamics. The objective is to represent the essential electrical and mechanical interactions of an electric powertrain using first-principles modeling combined with data-driven elements. The resulting model serves as a foundational platform for simulation, analysis, and future controller integration.

Contents

1 Introduction

Hardware-in-the-Loop (HIL) and Model-Based Design (MBD) are widely adopted methodologies in modern automotive development. Prior to controller deployment on embedded hardware, it is essential to validate the physical behavior of the system through simulation.

This project aims to develop a comprehensive plant model of a Battery Electric Vehicle (BEV) powertrain. The model captures the interaction between the electrical drive system and the vehicle's longitudinal dynamics. Emphasis is placed on physical correctness, modular structure, and real-time suitability, making the model appropriate for both academic study and industrial-oriented development workflows.

2 System Modeling (The Plant)

The plant model represents the physical behavior of the electric vehicle and is constructed using a combination of first principles equations and data-driven modeling techniques. Each subsystem is modeled independently and interconnected to form a complete powertrain architecture. This modular design improves readability, scalability, and allows future extensions such as control system integration or Hardware-in-the-Loop testing.

2.1 Battery and Motor Modeling

The battery is modeled using a lookup table that defines the output voltage as a function of operating conditions. This approach enables a more realistic representation of battery behavior compared to an ideal voltage source, while maintaining low computational complexity suitable for real-time simulation. The lookup table structure allows nonlinear voltage characteristics to be captured and provides flexibility for future enhancements such as state-of-charge dependency or load-based voltage variation.

The electric drive is modeled as a brushed DC motor. The electrical dynamics of the motor are governed by the following equation:

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

Here, V_{in} is the input voltage provided by the battery model, R_a and L_a are the armature resistance and inductance, and K_e is the back-electromotive force constant. The back-EMF term introduces a speed-dependent voltage drop that naturally limits the motor speed.

The mechanical torque generated by the motor is proportional to the armature current:

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

where K_t is the motor torque constant. This coupling between electrical and mechanical domains enables realistic drivetrain behavior under varying load conditions.

2.2 Transmission (Gearbox)

To provide sufficient torque at the wheels, a fixed-ratio gearbox is placed between the motor and the drivetrain. The gearbox converts the high-speed, low-torque output of the motor into low-speed, high-torque input at the wheels:

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

A gear ratio of $G = 10$ is selected to reflect a typical electric vehicle configuration. Mechanical losses within the gearbox are neglected in this model to focus on the dominant longitudinal vehicle dynamics.

2.3   Vehicle Longitudinal Dynamics

The vehicle body is modeled as a lumped point mass undergoing longitudinal motion. Newton's Second Law governs the vehicle dynamics:

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

The traction force is derived from the wheel torque and wheel radius, while resistive forces are primarily dominated by aerodynamic drag:

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

The nonlinear dependence of drag force on velocity introduces realistic acceleration behavior and results in a natural terminal velocity. Other effects such as rolling resistance and road gradients are neglected to maintain model simplicity and computational efficiency.

3   Conclusion

A complete plant model of an electric vehicle powertrain was successfully developed using Model-Based Design principles. The model integrates electrical, mechanical, and vehicle dynamics subsystems using a combination of first-principles equations and lookup table–based modeling. This work provides a robust foundation for future extensions including control system design, energy management strategies, and Hardware-in-the-Loop validation, aligning with standard automotive development practices.