Project Report

Performance & Efficiency Analysis of an Electric Vehicle Under Real-World Conditions

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1. Title Page

Project Title: Performance & Efficiency Analysis of an Electric Vehicle Under Real-World Conditions

Course: Advanced EV Design & Simulations with MATLAB & Simscape
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2. Abstract

This project focuses on simulating and analyzing the performance and efficiency of an electric vehicle (EV) under real-world driving conditions using MATLAB Simulink and Simscape. The study integrates road load modeling, power electronics design, and battery system analysis to evaluate the overall efficiency and energy consumption of the vehicle.

A representative drive cycle was used to capture real-world driving patterns. The results highlight the effect of aerodynamic drag, rolling resistance, and gradient resistance on torque and power requirements. The power electronics design was analyzed through converter and inverter simulations to assess switching performance, voltage ripple, and waveform quality. Additionally, a lithium-ion battery pack was modeled, and its State of Charge (SOC), thermal behavior, and fault response were studied.

The findings emphasize that accurate modeling and simulation help optimize EV performance, reduce energy consumption, and improve efficiency, thereby supporting the development of sustainable transportation solutions.

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3. Introduction

The global transition toward sustainable transportation has significantly increased interest in electric vehicles (EVs). Compared to internal combustion engine vehicles, EVs offer reduced emissions, higher efficiency, and lower operating costs. However, the design and optimization of EV systems require extensive testing, which can be time-consuming and expensive.

Simulation platforms such as MATLAB Simulink and Simscape provide an efficient way to model, analyze, and validate EV systems. Through simulation, engineers can test different driving cycles, evaluate battery behavior, design efficient power electronics, and optimize vehicle parameters without the need for costly prototypes.

In this project, a complete EV system is modeled to evaluate its performance under real-world conditions. Road load forces, power electronics, and battery systems are integrated to analyze energy consumption and efficiency improvements.

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4. Drive Cycle Selection & Road Load Analysis

Drive Cycle Selection

A standard urban drive cycle was selected to replicate real-world driving behavior involving frequent acceleration, deceleration, and idle conditions. Such cycles are widely used to assess EV energy consumption and efficiency.

Road Load Forces

The motion of a vehicle is opposed by three primary forces:

1. **Aerodynamic Drag Force (F_d):**

Fd=12·ρ·Cd·A·v2F_d = \frac{1}{2} \cdot \rho \cdot C_d \cdot A \cdot v^2Fd=21·ρ·Cd·A·v2

Where:

- ρ = air density
- C_d = drag coefficient
- A = frontal area
- v = vehicle velocity

2. **Rolling Resistance Force (F_r):**

Fr=Cr·m·gF_r = C_r \cdot m \cdot gFr=Cr·m·g

Where:

- C_r = rolling resistance coefficient
- m = mass of vehicle
- g = gravitational acceleration

3. **Gradient Resistance Force (F_g):**

Fg=m·g·sin(θ)F_g = m \cdot g \cdot \sin(\theta)Fg=m·g·sin(θ)

Where θ is the road gradient.

The total tractive effort required is:

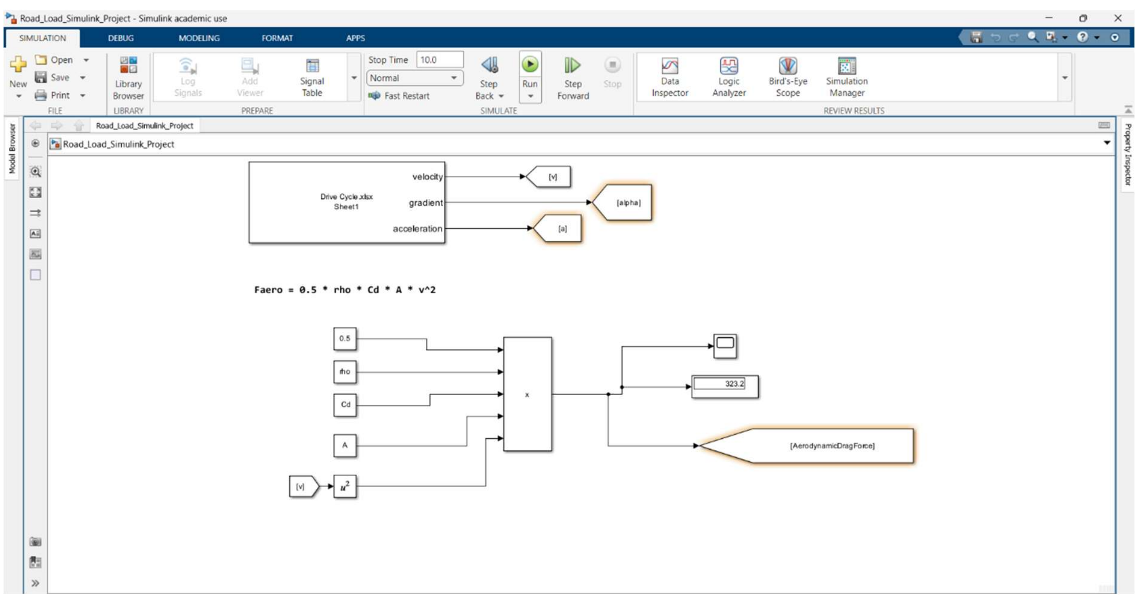
Ft=Fd+Fr+FgF_t = F_d + F_r + F_gFt=Fd+Fr+Fg

The torque (T) and power (P) required at the wheels are then calculated as:

T=Ft·rηT = \frac{F_t \cdot r}{\eta}T=ηFt·r P=Ft·vP = F_t \cdot vP=Ft·v

Where r is wheel radius and η is drivetrain efficiency.

These calculations establish the foundation for energy consumption analysis under the chosen drive cycle.



OUTPUT : Drive Cycle and Road Load Analysis

5. Vehicle Modeling Architecture (Simulink/Simscape)

The EV system was modeled using MATLAB Simulink and Simscape, with the following major components:

- **Electric Motor:** A Permanent Magnet Synchronous Motor (PMSM) was modeled due to its high efficiency and torque density.
- **Inverter:** A three-phase inverter controlled the motor's power flow using pulse-width modulation (PWM).
- **Battery Pack:** A lithium-ion battery pack was modeled to provide traction energy.
- **Road Load Forces:** Blocks representing aerodynamic drag, rolling resistance, and gradient resistance were included.

The interconnected model allows real-time simulation of vehicle dynamics under the drive cycle.

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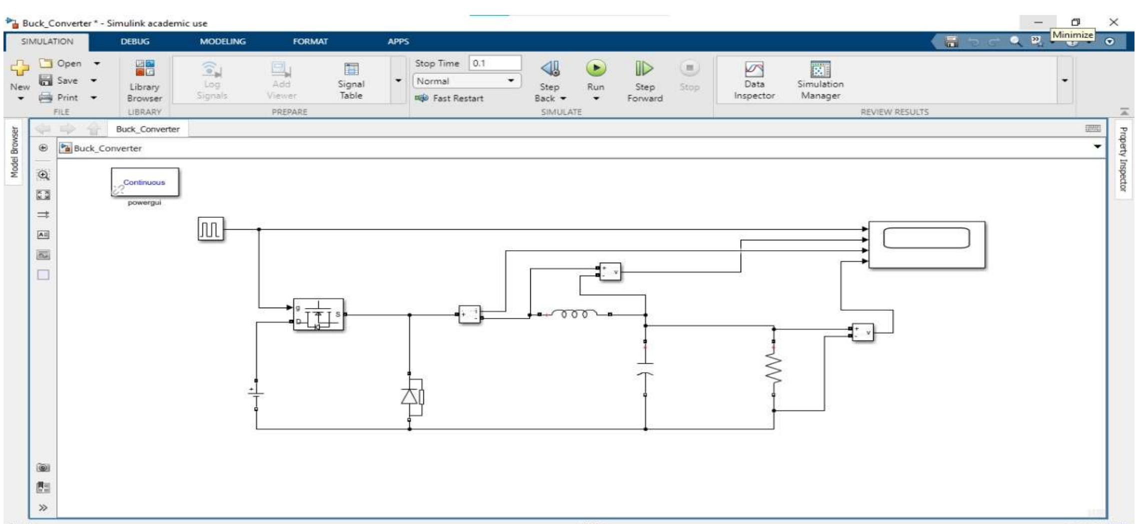
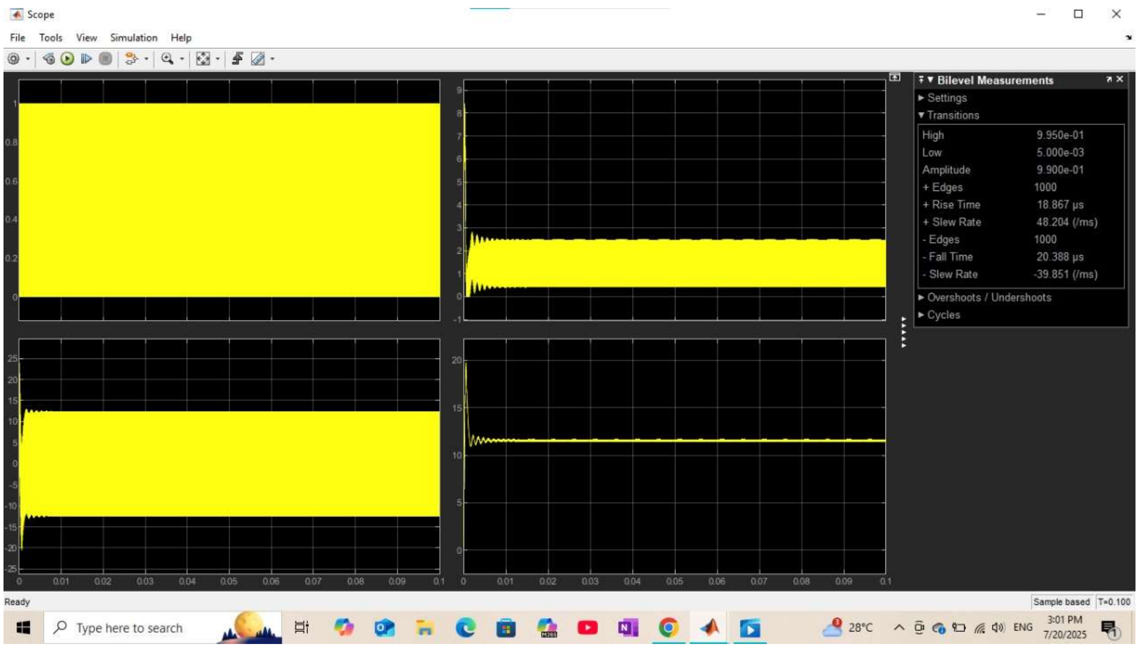
6. Power Electronics Design

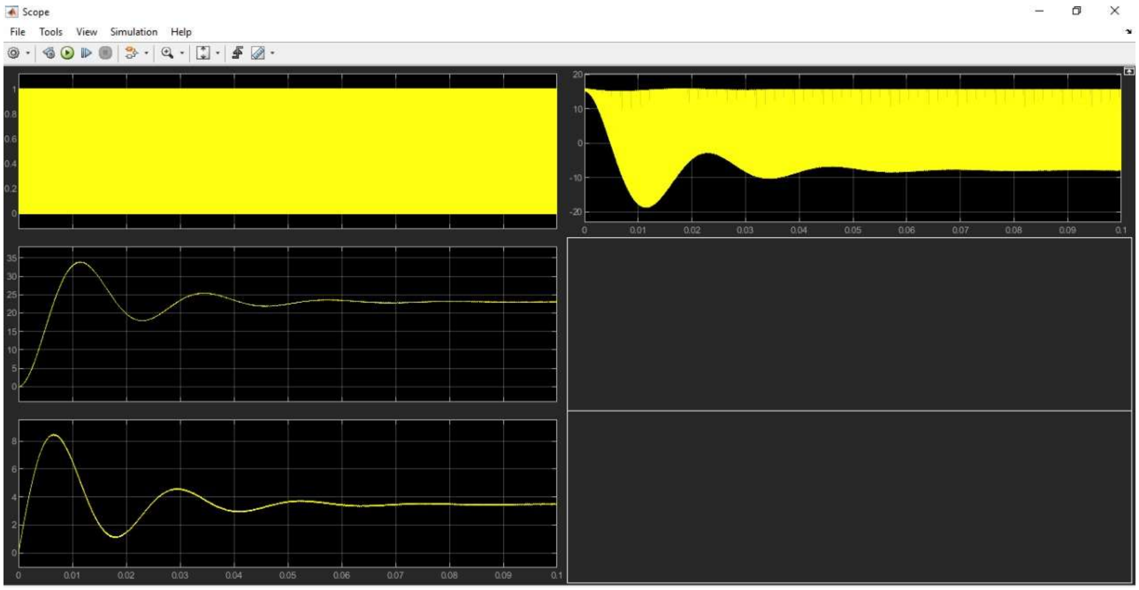
Power electronics play a crucial role in energy management within EVs. The simulations included:

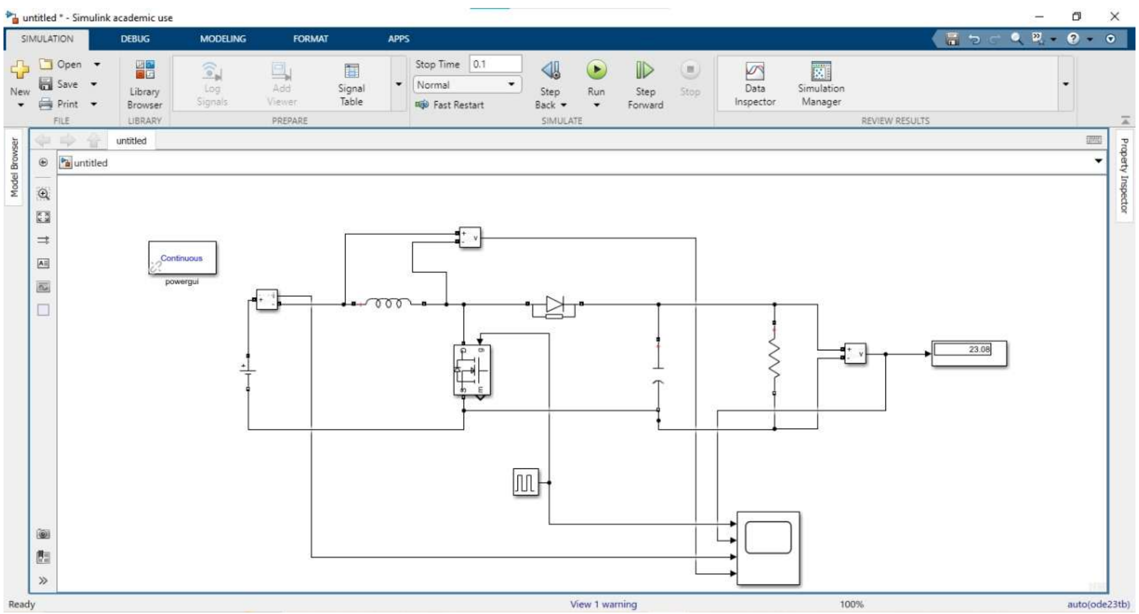
- **DC-DC Converters:** Buck, Boost, and Buck-Boost converters were tested to regulate voltage levels between the battery and motor drive.
- **Inverter:** A three-phase inverter supplied AC power to the PMSM motor.



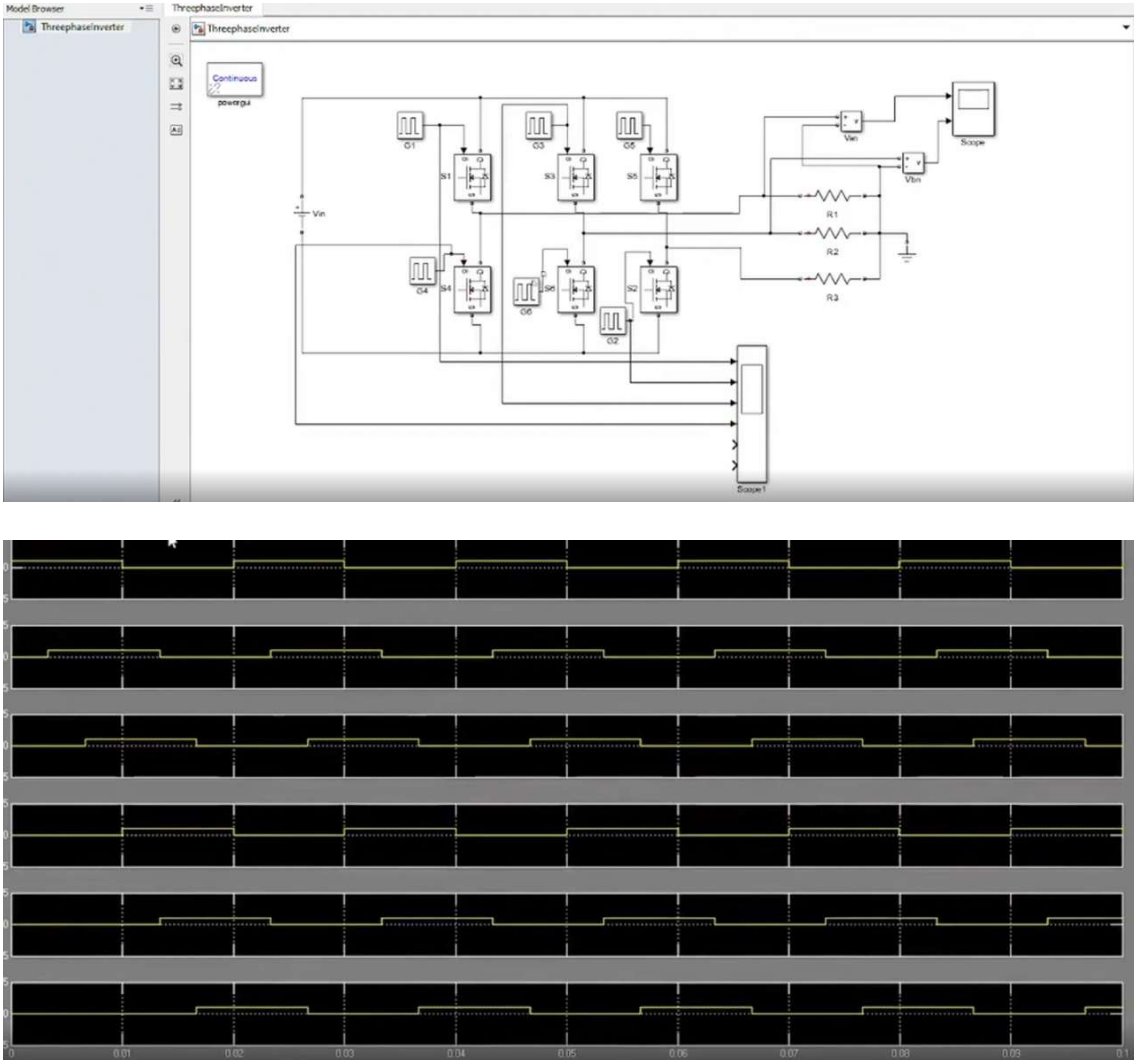
BUCK Converter Simulation and Output







Boost Converter and Output



Three Phase Inverter and Output

Key performance indicators such as voltage ripple, switching frequency, and current waveform quality were analyzed. The inverter demonstrated sinusoidal output waveforms, while the converters maintained stable voltage levels under load variations.

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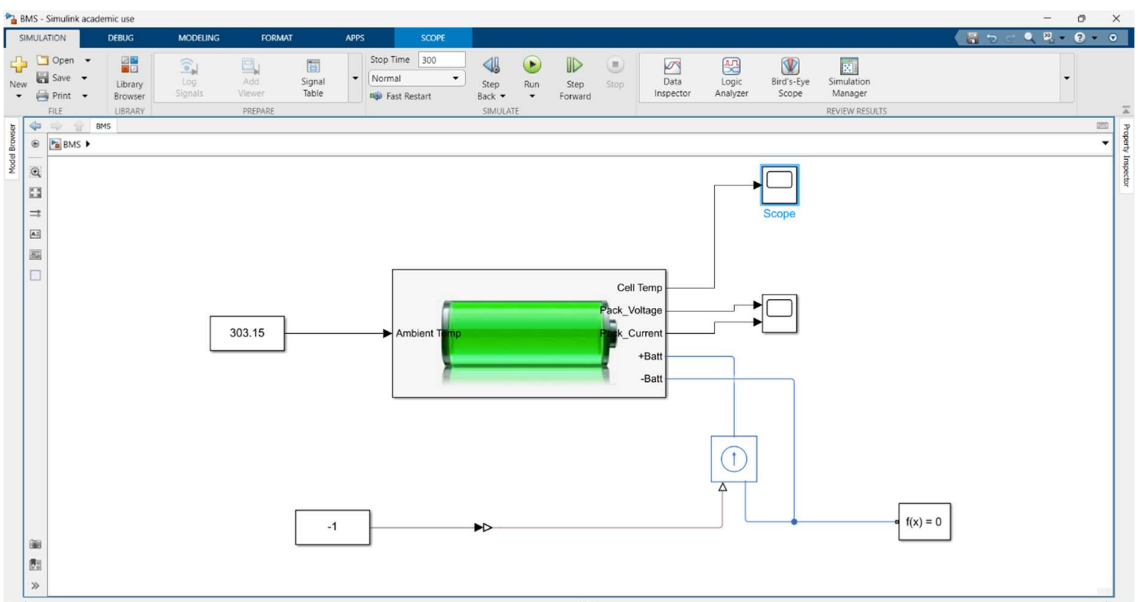
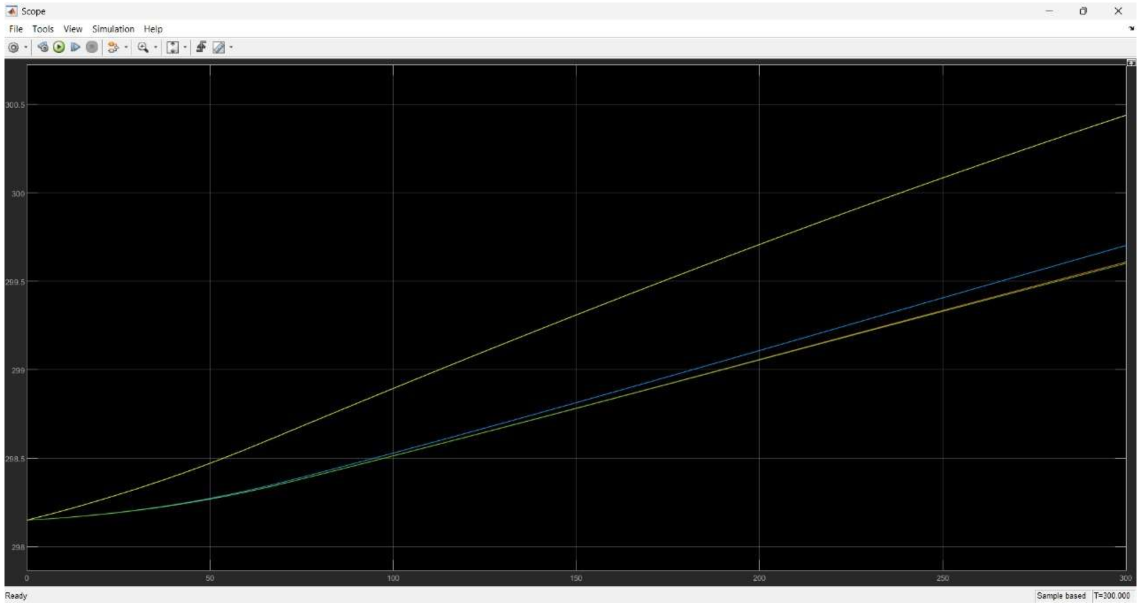
7. Battery Pack Modeling & BMS Integration

A lithium-ion battery pack was modeled due to its high energy density and long cycle life. The following aspects were studied:

- **State of Charge (SOC):** SOC was monitored throughout the drive cycle to estimate range and energy usage.
- **Thermal Behavior:** The battery temperature was analyzed to ensure safe operation.
- **Fault Logic:** Overcurrent and overcharge conditions were simulated to verify protective features of the Battery Management System (BMS).

The results indicated that SOC declined consistently with energy consumption, while thermal protection ensured safe operation.





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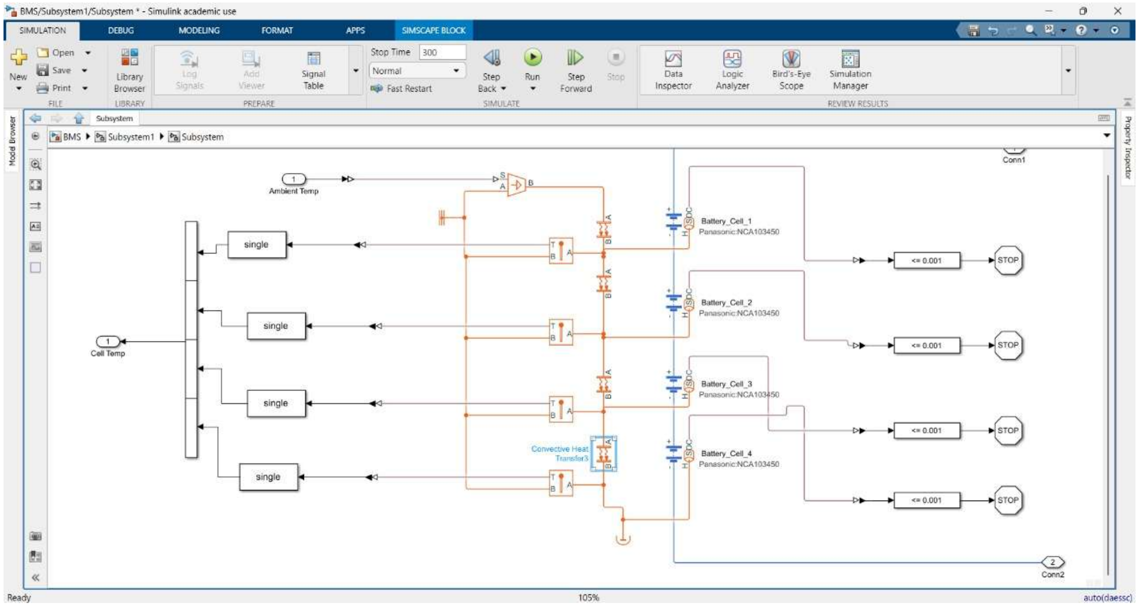
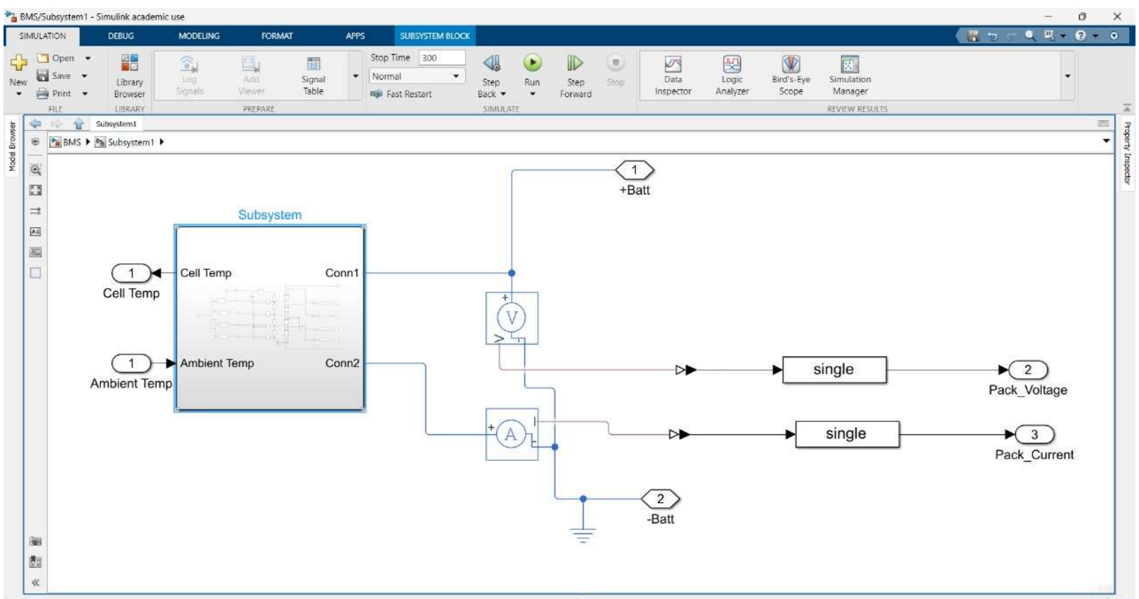
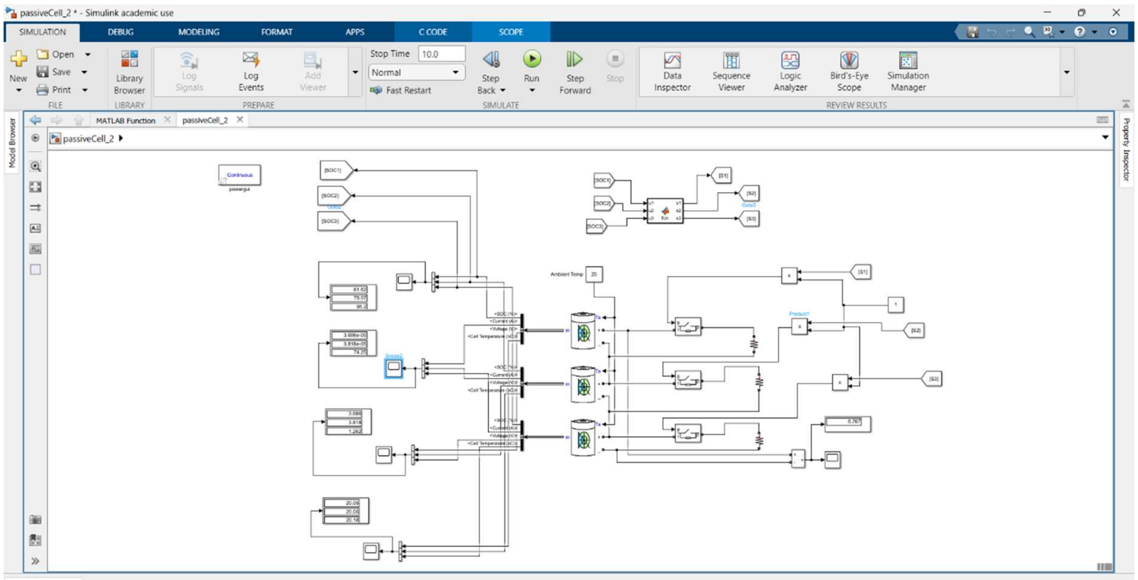




BMS Simulation and Output



Battert Pack Simulation

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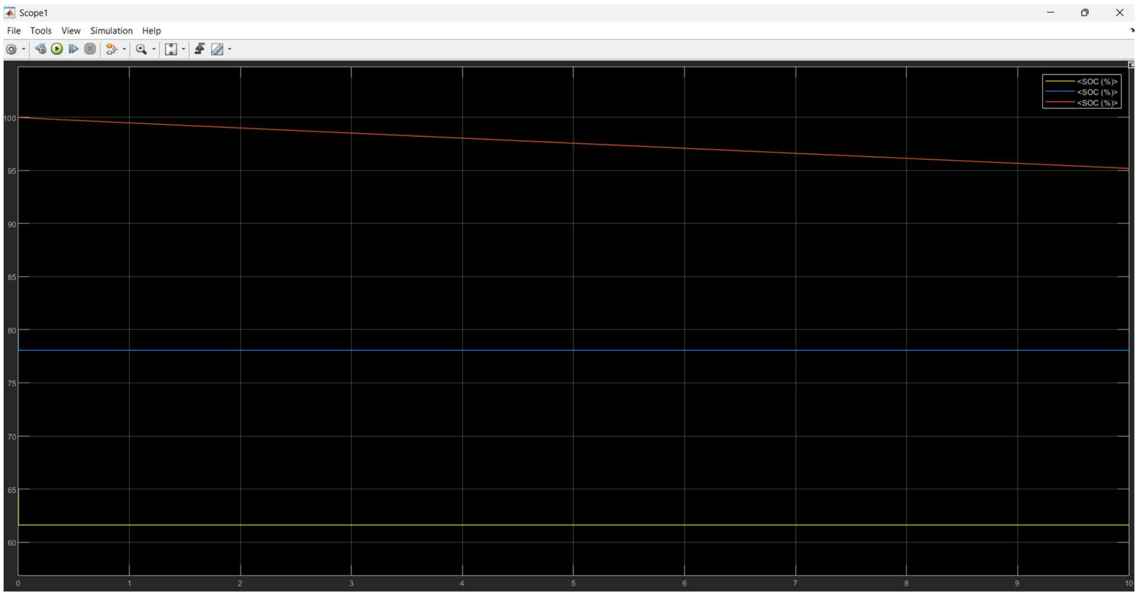

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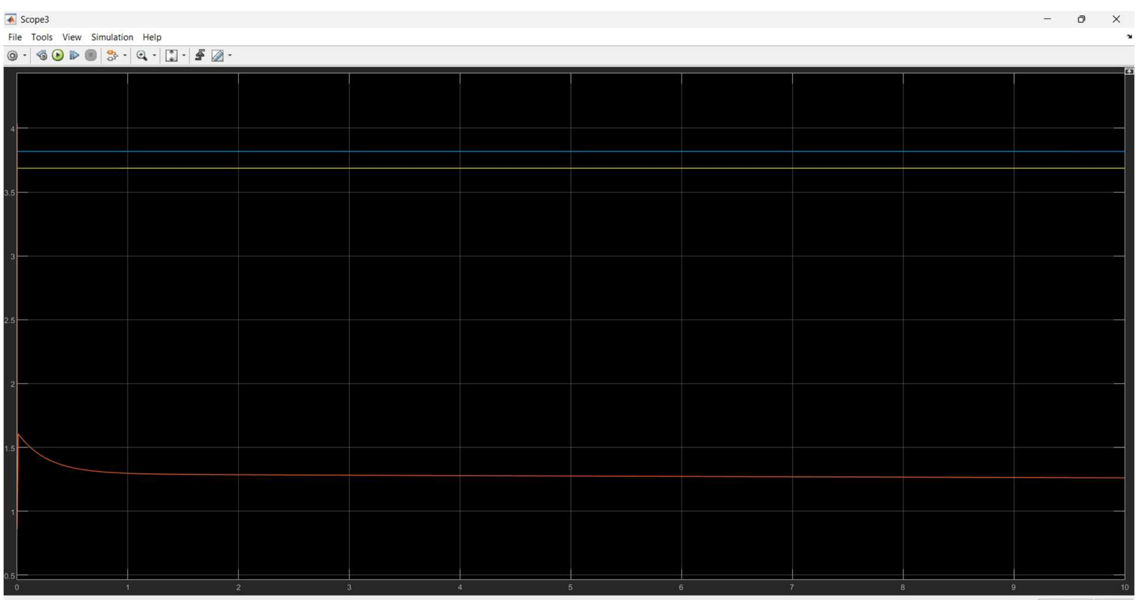

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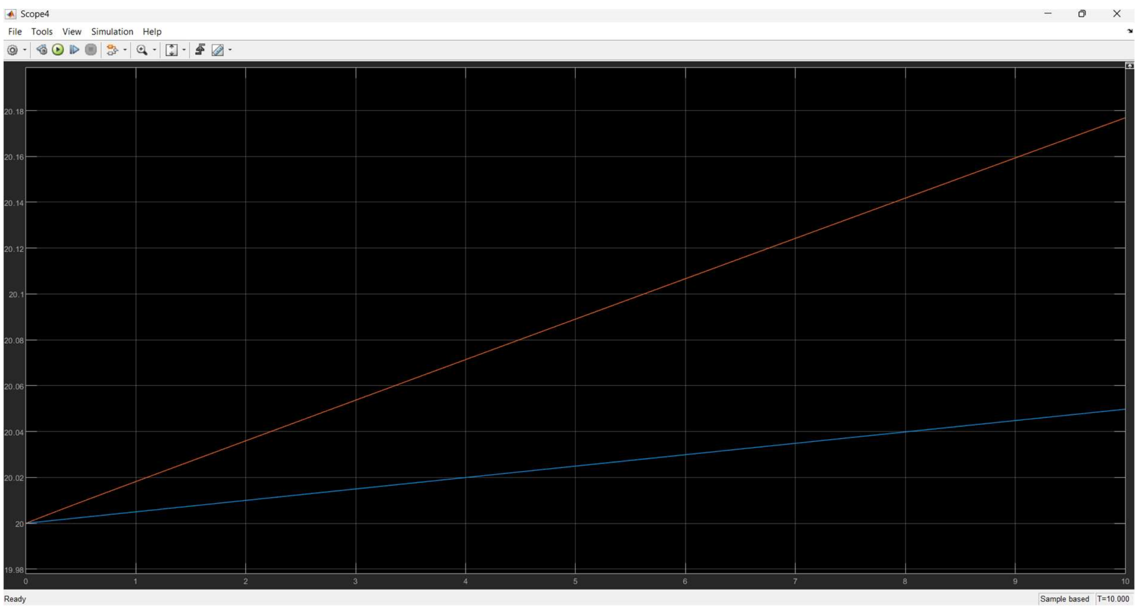

OUTPUT 4

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8. Challenges & Optimization

Challenges Encountered

- Convergence issues in Simulink during long drive cycle simulations.

- Parameter tuning for accurate motor and converter performance.
- Managing voltage ripple in DC-DC converters.

Optimization Strategies

- Controller gains were tuned to improve stability and response time.
- Vehicle mass and drag parameters were adjusted to optimize performance.
- Active cell balancing strategies improved battery longevity and reliability.

Outcomes

Optimization improved overall efficiency and reduced energy consumption, confirming the effectiveness of the adopted strategies.

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9. Conclusion

The project successfully demonstrated the simulation and performance analysis of an EV under real-world conditions using MATLAB Simulink and Simscape. Road load modeling quantified the forces acting on the vehicle, while power electronics ensured efficient energy conversion. Battery modeling provided insights into SOC, thermal management, and fault protection.

The study confirms that simulation is a powerful tool for EV design and optimization, enabling better efficiency and reliability before physical prototyping.
