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OPTIMIZATION OF BATTERY MANAGEMENT AND VEHICLE DYNAMICS IN BATTERY ELECTRIC VEHICLE USING SIMSCAPE

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ABSTRACT

This study focuses on simulating and analyzing the performance of a Battery Electric Vehicle (BEV) using MATLAB Simscape. The primary objective is to evaluate key performance parameters such as power consumption, battery performance, runtime, and temperature characteristics under different driving scenarios. The Simscape tool enables a detailed virtual modeling of the electric drive train, battery system, and vehicle dynamics. Various test scenarios, including different road profiles and driving cycles, are simulated to assess the impact of factors like regenerative braking, vehicle load, and ambient temperature on overall vehicle efficiency. Additionally, thermal management strategies for the battery system are evaluated to ensure optimal performance and longevity. The results provide insights into improving vehicle range, energy efficiency, and battery durability. This simulation-based analysis supports the optimization of BEV design, helping engineers make informed decisions about system architecture and performance enhancements.

Keywords: Battery Electric Vehicle (BEV), MATLAB Simscape, Thermal Management, Regenerative Braking, Vehicle Dynamics, Battery Efficiency.

I. INTRODUCTION

Recently, there has been a surge in interest in battery electric vehicles (BEVs) due to the growing need for environmentally friendly transportation options due to their low emissions, energy efficiency, and potential to reduce dependency on fossil fuels. Engineers and researchers must simulate and analyze the behavior of BEVs under varied settings in order to guarantee optimal performance and efficiency. In this project, we will utilize MATLAB Simscape to simulate the dynamic performance of a BEV. MATLAB Simscape provides a robust platform to model, simulate, and analyze the complex interconnections between an electric vehicle's battery, electric motor, power electronics, and thermal management systems. Through this simulation, we aim to gain insights into the vehicle's energy consumption, range, power train efficiency, and thermal behaviour under different driving conditions and battery states.

Objectives

The objective of this study is to simulate and analyze the performance of a Battery Electric Vehicle (BEV) using MATLAB Simulink and Simscape. This includes building a comprehensive virtual model of the battery, drivetrain, and related parts of the BEV in order to comprehend how it behaves dynamically under different driving scenarios. The simulation aims to assess key performance metrics such as energy consumption, battery state-of-charge (SOC), thermal characteristics, and range. By modeling the interactions between the electric motor, battery, and vehicle dynamics, the study aims to identify factors that influence efficiency and overall performance. Additionally, the simulation will provide insights into how different driving cycles, road profiles, and thermal management strategies impact the vehicle's operation. The results will aid in optimizing the design and performance of the BEV, providing a foundation for further improvements in electric vehicle technology.

II. METHODOLOGY

To simulate and analyze the performance of a Battery Electric Vehicle (BEV) using MATLAB and Simulink (Simscape), you can follow a structured methodology. This approach allows for creating a detailed virtual model, testing different conditions, and optimizing the design for better performance. Here's a step-by-step methodology:

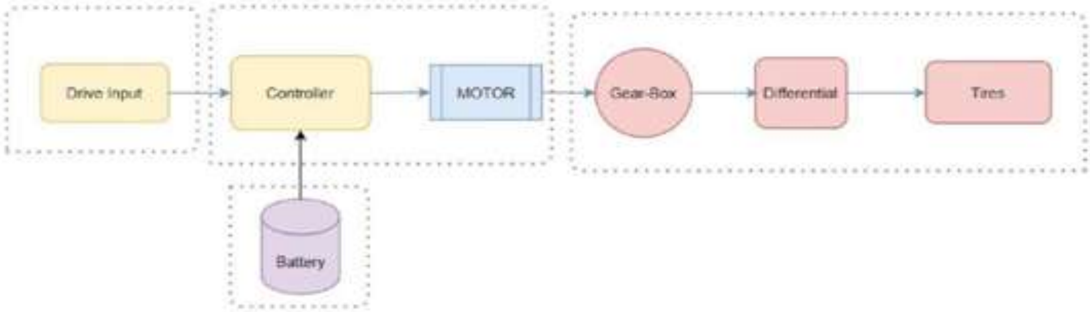

Fig 1: Battery Electric Vehicle

1. Model Development in MATLAB Simulink:

The simulation of the Battery Electric Vehicle (BEV) begins with the development of a virtual model using MATLAB Simulink and Simscape libraries. The process involves creating a detailed vehicle model, incorporating components such as the battery pack, electric motor, power electronics, and drivetrain. Each subsystem is defined using the Simscape blocks, which provide a physical modeling environment for representing the mechanical, electrical, and thermal aspects of the system. The battery model is designed to reflect the specific characteristics of the battery cells, such as state-of-charge (SOC), voltage, temperature, and thermal dynamics.

2. Defining Simulation Parameters

To accurately replicate real-world conditions, various parameters are defined for the simulation, including the vehicle's weight, aerodynamic drag coefficient, rolling resistance, and drive cycle. The drive cycle represents the speed and acceleration patterns that the BEV is expected to follow, the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), or New European Driving Cycle (NEDC). Input parameters for the battery model include capacity, voltage range, internal resistance, and thermal properties. These parameters play a crucial role in analyzing the performance, energy consumption, and thermal behavior of the battery under different driving conditions.

3. Implementation of Control Strategies

The next step involves implementing control strategies for energy management and vehicle dynamics. MATLAB Simulink allows for the integration of control algorithms, such as speed control, regenerative braking, and battery management. Regenerative braking is modeled to recover energy during deceleration and extend the range of the BEV. The Battery Management System (BMS) is configured to ensure optimal charging and discharging, monitor SOC, and protect against thermal runaway by managing cooling and heating mechanisms. These control strategies help in optimizing the vehicle's performance and efficiency.

4. Performance Analysis and Result Interpretation

After running the simulations, the results are analyzed to evaluate the BEV's performance in terms of range, energy efficiency, and thermal stability. The output data includes the battery's SOC, voltage, temperature profiles, and overall energy consumption. Graphical analysis tools in MATLAB are used to visualize the impact of different drive cycles and thermal management methods on the vehicle's performance. The results help identify areas for potential optimization, such as improving energy recovery during braking or enhancing thermal management to increase the battery's efficiency and lifespan.

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III. MODELING AND ANALYSIS

To simulate and analyze the performance of a battery electric vehicle (BEV) in MATLAB Simulink, you can use Simscape, which provides a comprehensive set of tools for modeling the physical components of a vehicle, including batteries, electric motors, and vehicle dynamics. Here's a general approach to guide you through this process:

1. Set Up the Simulink Model

- To create a new Simscape model, open MATLAB and Select Simulink Tab and open New Simscape Page
- Add the required libraries:
  - Simscape for modeling physical components.
  - Simscape Electrical for electrical components like motors, batteries, and power converters.
  - Simulink for control logic and simulation of dynamic systems.

2. Modeling the Battery System

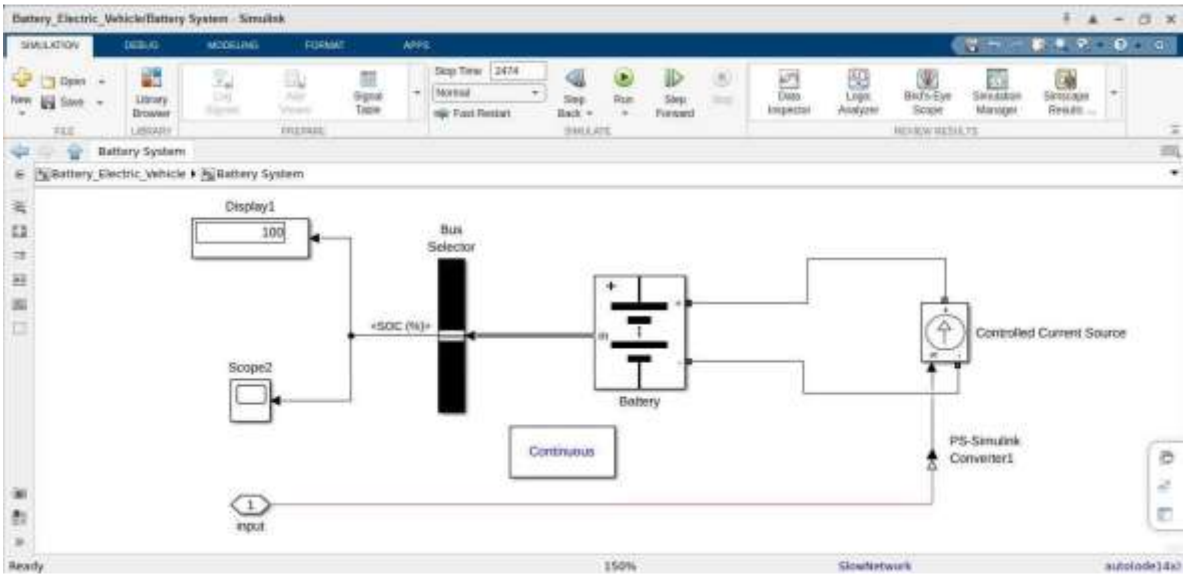

Fig 2: Battery Pack System

- Use the Battery block from the Simscape Electrical library to model the battery pack. Set parameters such as:
  - Battery type (e.g., Lithium-ion)
  - Nominal voltage and capacity
  - Internal resistance and thermal properties (if thermal effects are considered)
- Add a Battery Management System (BMS) to control charging and discharging rates and to monitor the battery's state of charge (SOC).
- **Battery Type Selection**: Selection of battery chemistry (e.g., Li-ion) based on application requirements.
- **Battery Model Parameters**: Inputting parameters like state-of-charge (SOC), voltage, capacity, and thermal characteristics.
- **Battery Pack Configuration**: Series and parallel combination of cells to meet voltage and energy requirements.

3. Modeling the Electric Motor

- Use the Permanent Magnet Synchronous Motor (PMSM) or Induction Motor block for simulating the electric motor.
- Define variables like efficiency, power rating, and torque-speed characteristics.
- Connect the motor to a Motor Controller (like an inverter) to manage the conversion of DC power from the battery to the motor's AC power source.

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Electric Motor and Controller Modeling:

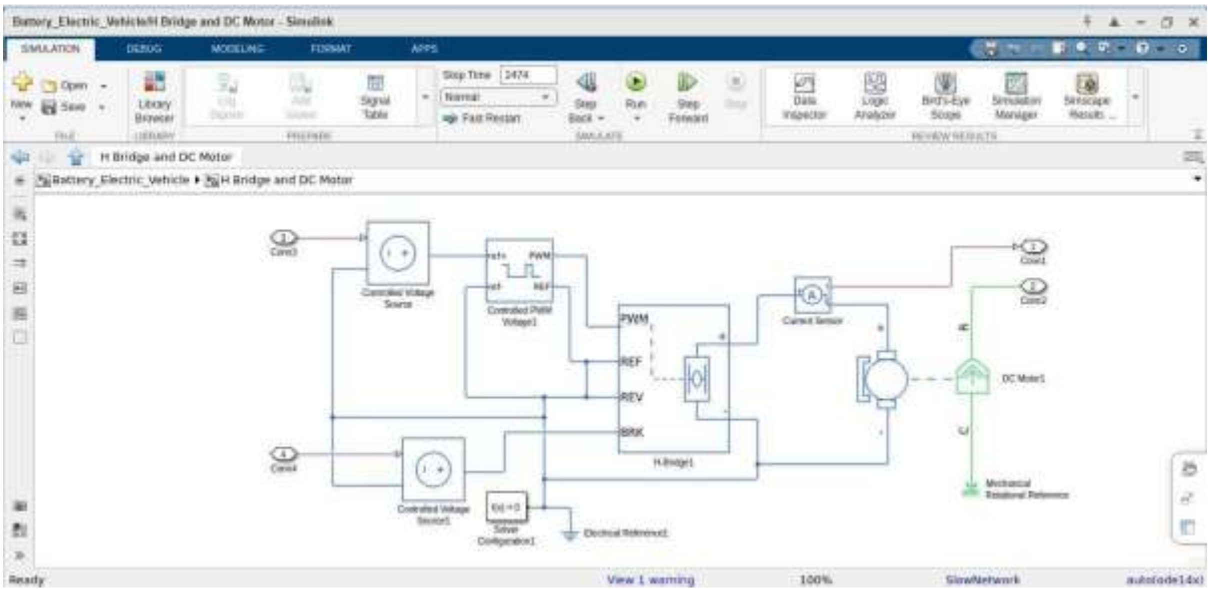

Fig 3: H-bridge Controller and DC Motor Subsystem

- Selection of Motor Type: Choose motor type (e.g., BLDC, PMSM) and configure motor parameters.
- Motor Control Strategy: Implement control strategies like field-oriented control (FOC) for efficient motor operation.

4. Vehicle Dynamics and Drivetrain

- Use the Vehicle Body block from the Simscape Driveline library to simulate the dynamics of the vehicle, including mass, drag, and road load.
- Connect the motor to the wheels using a Gear block or a direct drivetrain connection.
- Specify parameters like vehicle mass, tire characteristics, and aerodynamic drag coefficient.

Vehicle Dynamics Modeling:

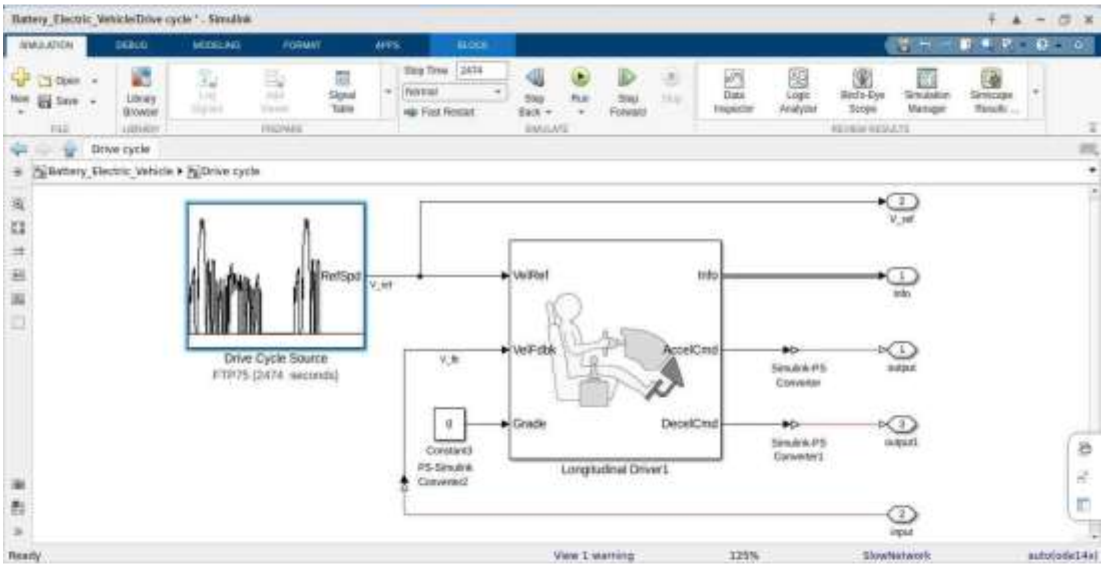

Fig 4: Drive Cycle Simulation Subsystem

- Modeling Vehicle Body: Use Simscape Multibody to represent the physical aspects of the vehicle.
- Resistance Forces: Model aerodynamic drag, rolling resistance, and vehicle mass.
- Driver and Controller Models: Implement a driver model to simulate driving patterns and a control system for vehicle speed regulation.

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5. Controller Design

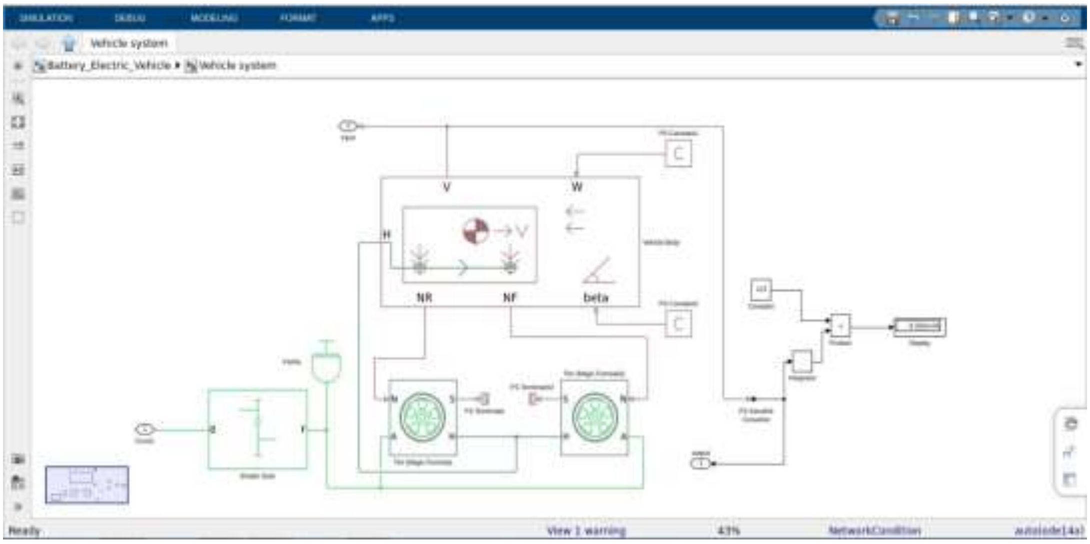

Fig 5: Vehicle Body Subsystem

- Implement a Speed Controller (PID or custom logic) to regulate the vehicle speed.
- The controller can adjust the torque command sent to the motor to achieve desired acceleration and speed.
- Integrate a Driver Model to simulate real-world driving conditions such as acceleration, braking, and road grades.

Power Electronics:

- DC-DC Converter Design: Model DC-DC converters for battery voltage regulation.
- Inverter Modeling: Design and configure an inverter for driving the electric motor.

6. Simulate the Model

- Set up a Drive Cycle (e.g., FTP-75 or WLTP) to simulate the vehicle performance under standard driving conditions.
- Run the simulation and observe the key performance metrics like:
  - State of Charge (SOC)
  - Battery voltage and current profiles
  - Vehicle speed and acceleration
  - Energy consumption and efficiency

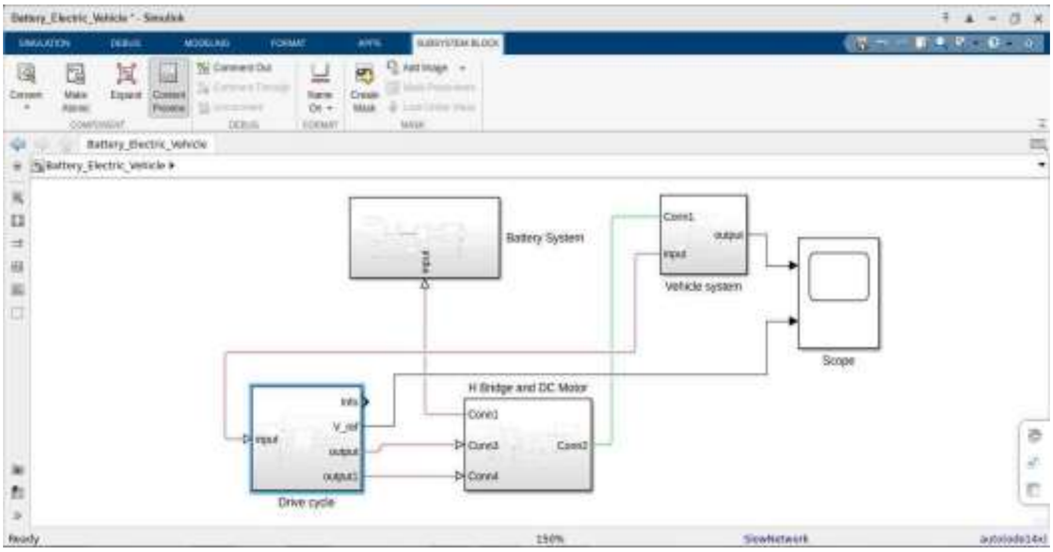

Fig 6: Battery Electric Vehicle System

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7. Analyze the Results

- Use MATLAB to analyze the simulation results by plotting parameters
- Compare the simulated results with real-world data or benchmarks to validate the model.

Parameters:

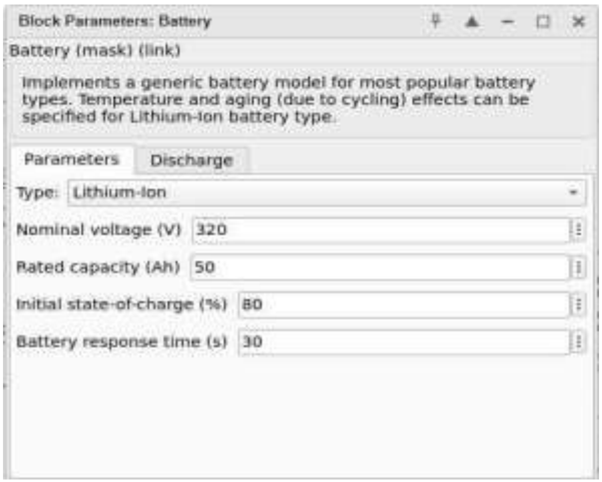

Fig 7: Battery Parameter

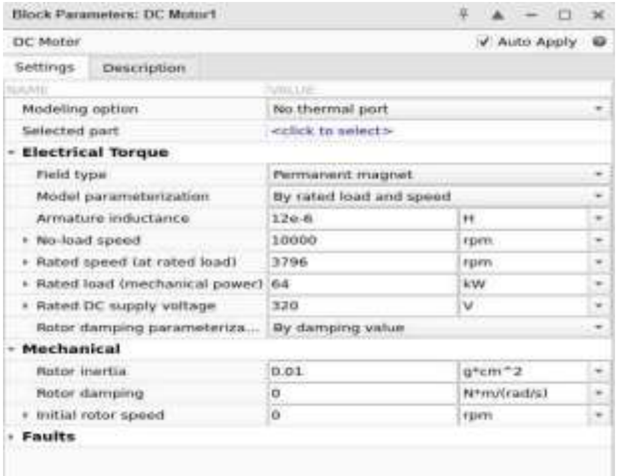

Fig 8: DC Motor Parameter

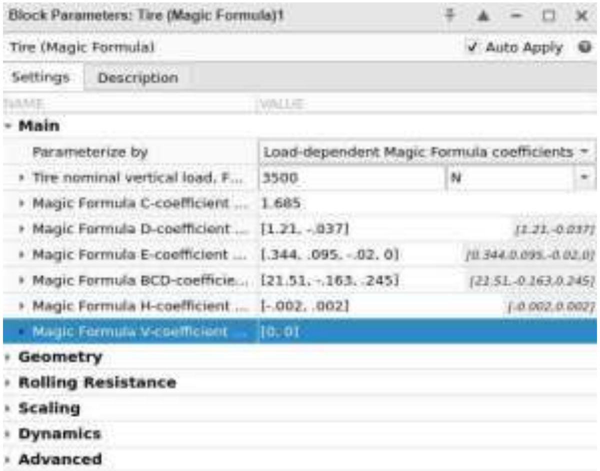

Fig 9: Tyre Parameter

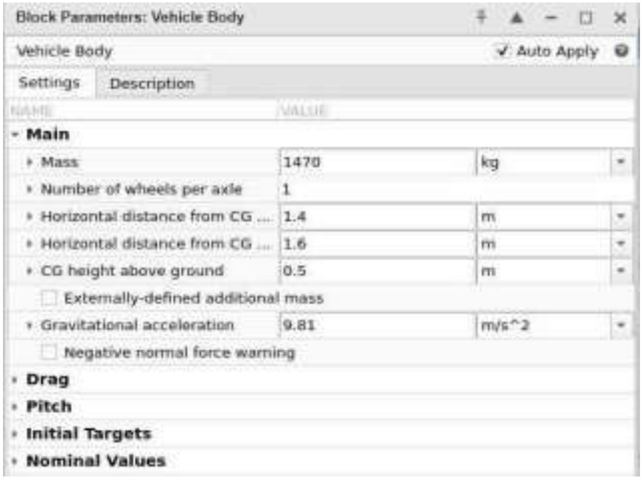

Fig 10: Vehicle Body Parameter

This approach provides a comprehensive overview of how to build a BEV model using Simulink and Simscape, focusing on key components like the battery, electric motor, and vehicle dynamics.

IV. RESULTS AND DISCUSSION

Performance:

Voltage & Current

The graphs show the current (A) and voltage (V) behavior of a lithium-ion battery in a battery electric vehicle (BEV) over time. Here's an analysis of each graph:

Current (A) Analysis:

- **Variation**: The current fluctuates between approximately -100 A and +100 A, indicating periods of both charging (negative current) and discharging (positive current). This is typical in a BEV during acceleration, regenerative braking, and deceleration.
- **Steady Period**: Around the 1200-2000 time mark, the current remains relatively stable, close to zero. This could correspond to a coasting phase where the vehicle is neither accelerating nor regeneratively braking.
- **Peaks**: The spikes in current could be due to periods of high acceleration (positive peaks) or aggressive regenerative braking (negative peaks).

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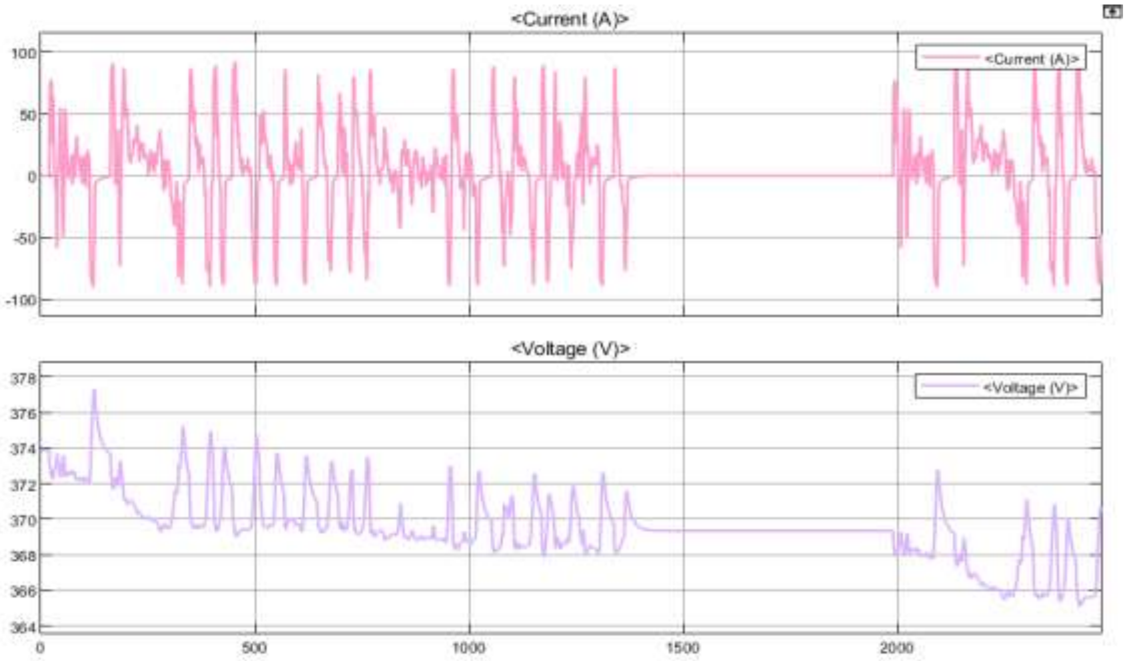

Fig 11: Voltage & Current

Voltage (V) Analysis:

- **Decreasing Trend**: The voltage starts higher (around 378 V) and gradually decreases to about 364 V, indicating a discharge as the battery powers the vehicle.
- **Fluctuations**: The fluctuations in voltage coincide with changes in current. High current draws (during acceleration) or regenerative charging (during braking) can cause temporary changes in voltage due to internal resistance.
- **Stable Region**: The voltage remains steady during the period where the current stabilizes around zero (between 1200 and 2000 on the time axis). This stability suggests a phase where the battery is neither under load nor actively charging.

Overall Behavior:

- The relationship between the current and voltage indicates the typical response of a lithium-ion battery in a BEV. During high current demand (acceleration), voltage drops slightly due to the internal resistance of the battery. During regenerative braking (negative current), voltage may rise as energy is fed back into the battery.
- The steady-state region could correspond to a cruising speed or idle condition, where power consumption is minimal, leading to little change in both current and voltage.

This analysis can provide insights into the driving patterns and the efficiency of regenerative braking in the BEV, as well as the state of charge (SoC) variation over time. Further interpretation would require understanding the time axis scale (e.g., seconds, minutes) and the specific vehicle's driving cycle.

Feedback Signal, Reference Signal & SOC

The graph shows three plots related to a Battery Electric Vehicle (BEV): feedback speed, reference speed, and State of Charge (SoC) over time. Here's a detailed analysis with considerations for their derivatives:

1. Feedback Speed (Red) and Reference Speed (Blue):

- **Feedback Speed**: This represents the actual speed of the vehicle as it responds to the control system.
- **Reference Speed**: This is the desired speed set by the controller.

Analysis:

- **Matching Trends**: Overall, the feedback speed follows the reference speed closely, indicating that the control system is effectively adjusting the vehicle's speed to match the desired setpoint.

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- **Transient Phases**: Where the reference speed increases or decreases, there is a delay before the feedback speed catches up. The derivative of speed (dv/dt), which is the acceleration, would be positive during the increase phases and negative during decreases.
- **Steady-State Regions**: When both feedback and reference speeds stabilize, the derivative of speed approaches zero (dv/dt=0). This indicates periods of constant speed, possibly representing cruising phases.
- **Control Dynamics**: Differences between feedback and reference speeds suggest a lag in response time. These deviations can be minimized through control tuning, making the feedback speed respond more rapidly to changes in reference speed.

2. State of Charge (SoC) Analysis:

- **Top Green Line**: Represents SoC over time, starting around 100% and gradually decreasing.
- **Bottom Green Line**: Indicates a secondary SoC metric, starting slightly below the top line and decreasing at a similar rate.

Analysis:

- **Decreasing Trend**: The SoC decreases progressively, indicating that the battery is discharging as the vehicle operates. The derivative of SoC (d(SoC)/dt) reflects the rate of battery depletion.
- **Fast Discharge Periods**: During periods of acceleration (where feedback speed increases), the SoC derivative is more negative, showing a faster discharge rate. This is due to higher power demand from the battery.
- **Lower Discharge Rates**: When the feedback speed stabilizes, the discharge rate decreases (d (SoC)/dt becomes less negative), indicating that the battery is consuming less power, possibly during steady driving or coasting phases.
- **Regenerative Braking Impact**: If regenerative braking is applied (negative current flow), we might see a slight increase or a less steep decline in SoC. This would show as a less negative d((SoC)/dt or even a brief positive value, though it appears that such effects are minimal here.

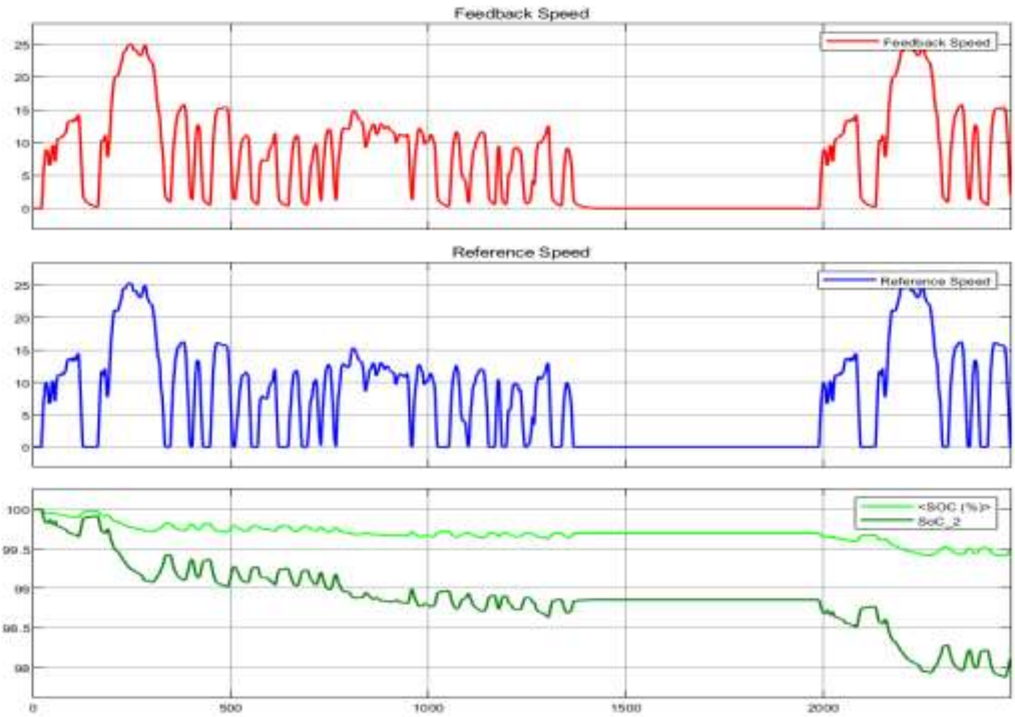

Fig 12: Feedback Signal, Reference Signal & SOC

Overall Derivative Insights:

- **Speed Derivatives**:
  - Positive derivative (dv/dt) indicates acceleration.

- Negative derivative (dv/dt) indicates deceleration or braking.
- Derivatives of feedback speed lag behind the reference speed, indicating response time of the control system.

- **SoC Derivatives**:
  - A more negative derivative indicates higher power consumption, likely during acceleration.
  - A less negative or flat derivative corresponds to steady power consumption, indicating efficient energy use during cruising.

Summary:

- The control system in the BEV effectively tracks the desired reference speed, though with some lag.
- The SoC behavior is consistent with expected discharge during driving phases, with variations in discharge rate based on speed changes.
- Understanding the rates of change (derivatives) in these plots helps optimize both the speed control system and energy management strategies in BEVs for better performance and range efficiency.

V. CONCLUSION

In the designed and analyzed study of the Battery Electric Vehicle (BEV) using a Model-Based System Design (MBSD) approach with MATLAB Simscape, the vehicle's performance was rigorously evaluated against the proposed requirements. The MBSD approach enabled a systematic and integrated modeling environment, allowing for the simulation and testing of various components such as the battery, motor, and control systems. Using MATLAB Simscape provided a detailed representation of the physical systems, facilitating accurate simulations of dynamic behaviors like acceleration, regenerative braking, and energy consumption. The simulation results, including speed control and State of Charge (SoC) variations, demonstrated that the BEV met the design criteria for efficient energy management and speed regulation. The feedback and reference speed closely aligned, indicating an effective control system response, while the battery's discharge pattern matched expected performance parameters, ensuring optimal range and power delivery. Overall, the MBSD approach proved valuable in designing a robust BEV model, enabling iterative testing and validation to achieve a balance between energy efficiency and vehicle performance.

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