ELECTRIC VEHICLE POWERTRAIN DEVELOPMENT: INSPIRED BY TATA NEXON EV CONFIGURATIONS

MINOR PROJECT WORK

For the partial fulfilment for the award of the major degree in

Electrical and Electronics Engineering

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DECLARATION

I hereby declare that the project report entitled " **Design and Analysis of Powertrain of Tata Nexon Electric Vehicle** " submitted by me to the National Institute of Technology Delhi during the academic year 2023-24 in partial fulfillment of the requirements for the award of Degree of Bachelor of Technology in Electrical and Electronics Engineering is a record of bonafide project work carried out under the guidance and supervision of Dr. Manoj Kumawat. I further declare that the work reported in this this project has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other University.

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ABSTRACT

The powertrain of an electric vehicle (EV) is a critical component that directly influences its performance and efficiency. This paper presents a detailed analysis of the powertrain components of an EV, focusing on key elements such as the vehicle body, permanent DC magnet motor, power converter (H-bridge) with regenerative braking, driver controller, and longitudinal driver. The input for the analysis includes various drive cycles such as the Worldwide harmonized Light vehicles Test Cycle (WLTC), New European Driving Cycle (NEDC), modified Indian drive cycle, and the specific Tata Nexon EV drive cycle.

The vehicle body serves as the structural foundation and provides the necessary support for mounting the powertrain components. The permanent DC magnet motor is a crucial part of the powertrain, responsible for converting electrical energy into mechanical energy to drive the vehicle. The power converter, implemented as an H-bridge, facilitates the control of the motor's speed and direction, as well as enables regenerative braking to recover energy during deceleration.

The driver controller is responsible for managing the operation of the powertrain components based on inputs such as the selected drive cycle and the desired vehicle performance. The longitudinal driver is a key component of the driver controller, regulating the vehicle's acceleration and deceleration based on the input signals.

Additionally, the analysis considers the battery pack and its State of Charge (SoC), which play a crucial role in determining the vehicle's range and overall performance. The SoC of the battery pack is monitored and controlled to ensure optimal utilization of the available energy and maximize the vehicle's efficiency.

Overall, this paper provides a comprehensive overview of the powertrain of an electric vehicle, highlighting the interplay between its various components and their impact on the vehicle's performance under different driving conditions and drive cycles.

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CHAPTER 1
INTRODUCTION

1.1 ELECTRICAL ASPECT OF EV

Electric vehicles (EVs) are essential for replacing internal combustion engine (ICE) vehicles due to their significant environmental benefits. EVs reduce air pollution and combat climate change by producing zero tailpipe emissions. They can be charged using renewable energy sources, promoting a greener energy mix. EVs are more energy-efficient than ICE vehicles, resulting in lower energy consumption and operating costs. Technological advancements in battery technology and charging infrastructure have made EVs more affordable and convenient. Transitioning to EVs enhances energy security by reducing dependence on imported oil. Additionally, EVs contribute to quieter urban environments by eliminating the noise generated by internal combustion engines[**?**]. While challenges remain, such as expanding charging infrastructure and addressing battery sustainability, the advantages of EVs make them indispensable for achieving a cleaner and more sustainable transportation system.

1.1.1 Traction Battery Pack

Hybrid and electric vehicles rely on a high voltage battery system, comprising multiple individual modules and cells that are strategically arranged in both series and parallel configurations. The cell, being the smallest unit, typically ranges from one to six volts and serves as a fundamental building block of the battery. These cells are combined into modules, wherein several cells are interconnected either in series to increase voltage or in parallel to boost capacity. Finally, a comprehensive battery pack is created by connecting these modules together, once again in either series or parallel arrangements[**?**].

(i) Nominal Voltage

Nominal voltage in a battery pack refers to the average or typical voltage level at which the battery operates during normal conditions. It is a standardized value that represents the approximate average voltage output of the battery when it is in use. This nominal voltage is often used as a reference point for designing and using electrical systems that rely on the battery pack's power supply.

For example, in a lithium-ion battery pack commonly used in electric vehicles, the nominal voltage of each cell might be around 3.6 to 3.7 volts. If the battery pack consists of multiple cells connected in series, the nominal voltage of the entire battery pack will be the sum of the nominal voltages of each individual cell.

It's important to note that the actual voltage of a battery pack may vary depending on factors such as charge level, temperature, and load conditions. Therefore, the nominal voltage provides a standard value to work with, but it should not be confused with the actual voltage output that can fluctuate during operation.

(ii) Rated Capacity

Rated capacity in a battery pack refers to the amount of electric charge that the battery is designed to store and deliver over a specific period. It is typically measured in ampere-hours (Ah) or milliampere-hours (mAh) and represents the total energy capacity of the battery pack when it is fully charged and discharged according to its intended use.

For instance, if a battery pack has a rated capacity of 100 Ah, it means it can theoretically deliver a current of 1 ampere (A) for 100 hours or 100 amperes for 1 hour, before being fully discharged. In practice, the actual capacity delivered by a battery pack may vary based on factors like discharge rate, temperature, and age of the battery.

Rated capacity is an essential specification for battery packs as it helps users understand how much energy can be stored and utilized before requiring recharging. It is crucial for estimating the range and run-time of devices or vehicles powered by the battery pack and is a fundamental parameter in designing electrical systems that rely on these energy storage units.

Total voltage = (Nominal voltage of each cell) x (Number of cells connected in series)

(iii) Lithium ion Battery

Lithium-ion battery packs have emerged as the dominant energy storage systems across various applications, including aircraft, electric vehicles, portable devices, and other equipment that require a reliable, high-energy-density, and lightweight power source. These batteries offer several advantages, such as a high energy density, longer cycle life, and lower self-discharge rates compared to other battery technologies.

(iv) SoC

The Soc, or State of Charge, refers to the current level of charge in the vehicle's battery pack, typically expressed as a percentage of the total capacity. It's a critical piece of information for both the driver and the vehicle's systems to manage energy usage effectively and plan trips accordingly.

The SoC is expressed as a percentage that indicates how much capacity is left in the battery relative to its maximum capacity when fully charged1. For example, if an EV battery has a 50 percent SoC, it means there is still 50 percent of the total battery capacity available to use1.For EVs, knowing the SoC is akin to knowing how much fuel is left in a traditional gasoline car's tank.

Moreover, the vehicle's onboard systems, including the Battery Management System (BMS) and powertrain control, rely on the State of Charge information to optimize energy usage. For example, the powertrain controller might adjust motor power output based on the battery's current charge level to maximize efficiency or activate energy-saving features when the SoC is low to ensure the vehicle can reach its destination.

(v) SoH

SoH stands for State of Health. The State of Health refers to the overall condition and health of the vehicle's battery pack. It is a measure of how well the battery can still hold and deliver energy compared to its original capacity when it was new.

It's importance:

1. Capacity Degradation: Over time, due to factors like usage patterns, charging habits, temperature variations, and the number of charge-discharge cycles, the battery's capacity gradually decreases. State of Health quantifies this degradation, usually expressed as a percentage of the battery's original capacity. For instance, if a battery that originally had 100 kWh capacity now only holds 80 kWh, its State of Health would be 80

2. Performance Estimation: Understanding the State of Health helps estimate the remaining usable capacity of the battery. This information is crucial for predicting the driving range of the vehicle accurately. It allows drivers to plan their journeys better, considering factors like range anxiety and the need for recharging.

3. Battery Management: Electric vehicles employ sophisticated Battery Management Systems (BMS) that monitor various parameters of the battery pack, including State of Health. The BMS uses this information to optimize charging and discharging processes, implement strategies for prolonging battery life, and ensure safe operation.

4. Resale Value and Warranty: State of Health also influences the resale value of electric vehicles. A battery pack with higher State of Health retains more value since it offers better performance and range. Additionally, warranties for EV batteries often specify a minimum State of Health threshold below which the

manufacturer is obligated to replace or repair the battery pack.

5. Maintenance and Service: Manufacturers and service centers may use State of Health data to determine when maintenance or replacement of the battery pack is necessary. This proactive approach helps prevent unexpected failures and ensures the vehicle's reliability over its lifespan.

(vi) Battery Management System

The Battery Management System (BMS) in an electric vehicle (EV) is a crucial component responsible for managing and monitoring the health and performance of the vehicle's battery pack.

Its functions:

1. State of Charge (SoC) Monitoring: The BMS continuously measures and tracks the State of Charge of each individual cell within the battery pack. This information helps drivers estimate remaining range accurately and prevents overcharging or deep discharging, which can damage the battery.

2. State of Health (SoH) Monitoring: BMS evaluates the State of Health of the battery by monitoring parameters such as capacity degradation, internal resistance, and cell voltage imbalances. This data helps assess the long-term health and performance of the battery pack.

3. Cell Balancing: BMS ensures that all cells in the battery pack are charged and discharged evenly. It performs cell balancing by redistributing energy among cells to prevent overcharging of some cells and undercharging of others, which can improve overall battery longevity and performance.

4. Thermal Management: BMS monitors and controls the temperature of the battery pack to ensure optimal operating conditions. It may activate cooling or heating systems to prevent overheating or cold-related performance degradation, thereby enhancing safety and longevity.

5. Safety Features: BMS incorporates safety mechanisms to protect the battery pack from overcharging, over-discharging, short circuits, and thermal runaway. It can disconnect the battery from the vehicle in case of a fault or emergency to prevent damage or mitigate risks.

6. Performance Optimization: BMS optimizes the performance of the battery pack by implementing charge/discharge control algorithms tailored to specific driving

conditions and user preferences. This helps maximize driving range, efficiency, and overall vehicle performance.

7. Data Logging and Communication: BMS records data related to battery performance, including charging history, temperature profiles, and fault codes. It communicates this information to the vehicle's onboard systems, allowing for real-time monitoring, diagnostics, and remote management.

1.1.2 Powertrain

The powertrain of an electric vehicle (EV) encompasses all the components responsible for generating power and transferring it to the wheels to propel the vehicle. In an electric vehicle, the powertrain is fundamentally different from that of a traditional internal combustion engine vehicle [1]. In this paper, we have designed and analysed the powertrain model on Tata Nexon EV configurations.

(i) Vehicle body

The vehicle body refers to the structural framework of an automobile, excluding the powertrain, chassis, and interior components. It serves as the outer shell that encloses the vehicle's occupants, engine, and other essential systems. The body provides structural support, aerodynamic efficiency, and protection from environmental elements. It also houses components such as doors, windows, and the trunk, contributing to the vehicle's overall appearance and functionality.

(ii) DC Motor

A permanent DC motor is an electric motor that operates on direct current (DC) power and utilizes permanent magnets to generate the magnetic field required for motor operation. These motors are commonly used in electric vehicles (EVs) and hybrid vehicles due to their simplicity, reliability, and efficiency. Permanent DC motors are known for their high starting torque, making them suitable for applications where rapid acceleration is required [2]. They are often used in Light Electric Vehicles (LEVs), such as electric scooters, bikes, and low-speed electric cars.

(iii) Power Converter

An H bridge is an electronic circuit that is commonly used in power electronics to control the direction and speed of DC motors. It consists of four switching elements (typically transistors or MOSFETs) arranged in an "H" configuration. By controlling the switching states of these elements, an H bridge can reverse the polarity of the voltage applied to a DC motor, allowing it to rotate in both forward and reverse directions. H bridges are frequently used in motor control applications, including electric vehicles, robotics, and industrial automation, as they provide efficient and precise control over motor operation.

(iv) Drive Controller

A drive controller, also known as a motor controller or motor drive, is an electronic device that regulates the operation of an electric motor. It controls parameters such as motor speed, torque, and direction by adjusting the voltage and current supplied to the motor. In electric vehicles, the drive controller plays a crucial role in converting the DC power from the battery into the appropriate signals to drive the electric motor. It may incorporate features such as regenerative braking control, thermal management, and communication interfaces for integration with vehicle systems. The drive controller ensures smooth and efficient motor operation while optimizing energy usage and vehicle performance.

1.1.3 Drive Cycles

A drive cycle of electric vehicles is a series of data points representing the speed of a vehicle versus time. In simpler terms, it's a velocity vs time graph of a vehicle. Drive cycles for electric vehicles (EVs) refer to standardized tests or simulated driving scenarios used to evaluate the performance, energy consumption, and emissions of electric vehicles under various operating conditions. These cycles are designed to replicate typical driving patterns and conditions encountered by vehicles in real-world use.

(i) WLDC

The WLDC (World Light Duty Vehicle Test Cycle) is a global drive cycle used for testing the fuel economy and emissions of light-duty vehicles, including electric vehicles (EVs). It was developed by the United Nations Economic Commission for Europe (UN-ECE) as part of the Worldwide Harmonized Light Vehicles Test Procedure (WLTP). The WLDC is designed to represent typical driving conditions encountered by vehicles in urban, suburban, and highway environments.

(ii) FTP75

The FTP-75 (Federal Test Procedure 75) drive cycle is a standardized test cycle used primarily in the United States to evaluate the fuel economy and emissions of light-duty vehicles, including electric vehicles (EVs). It was developed by the Environmental Protection Agency (EPA) for certification and compliance testing of vehicles sold in the U.S. market.

1.2 MECHANICAL ASPECT OF EV

The mechanical aspects of electric vehicles (EVs) encompass critical components such as chassis, suspension, braking, steering, wheels, and tires, all designed to ensure efficient and safe operation. EVs typically feature regenerative braking systems for energy recapture, along with aerodynamic body designs and lightweight materials to maximize efficiency and range. Electric motors often require simplified drivetrains, while cooling systems manage heat generated by motors and battery packs[**?**]. Safety features, including robust structural designs and advanced driver assistance systems, are integrated to enhance occupant protection. These mechanical elements collectively contribute to the performance, reliability, and sustainability of electric vehicles in modern transportation.

1.2.1 Vehicle dynamics

Vehicle dynamics modeling using Newton's Laws of Motion (NLM) offers a systematic framework to comprehend the intricate interplay of forces shaping the motion and behavior of electric vehicles (EVs). By conceptualizing the vehicle as a load influenced by longitudinal forces, one gains insights into how propulsion from the electric motor, along with resistance forces like aerodynamic drag and rolling resistance, dictate the vehicle's acceleration and deceleration dynamics. Moreover, the inclusion of regenerative braking during deceleration adds a layer of complexity, illustrating how energy can be recaptured and fed back into the battery system. This holistic understanding of forces enables accurate predictions of vehicle performance metrics such as acceleration, energy consumption, and driving range, crucial for optimizing EV design and operation.

In addition to these fundamental forces, factors such as weight distribution, suspension design, and tire characteristics play pivotal roles in shaping the stability and handling of EVs. These elements directly influence how the vehicle responds to steering inputs, corners, and various driving conditions. Furthermore, integrating vehicle dynamics modeling with advanced control systems offers avenues to enhance performance, safety, and efficiency. By dynamically adjusting power delivery, braking, and suspension settings, control systems optimize vehicle dynamics in real-time, ensuring a seamless and safe driving experience while maximizing energy efficiency. Overall, a comprehensive understanding and integration of vehicle dynamics into EV design and operation are essential for unlocking the full potential of electric mobility[3].

1.2.2 Configurations

The important parameters that directly or indirectly influences the performance of powertrain are listed below along with their values:

Table 1.1: Mechanical configuration

Parameter	Value
Kerb weight (kg)	1400
Payload (kg)	70
Total weight (kg)	1470
Coefficient of rolling resistance	0.015
Acceleration due to gravity (m/s^2)	9.81
Rolling resistance force (N)	216.3105

Table 1.2: Air drag configuration

Parameter	Value
Air density (kg/m^3)	1.225
Width (m)	1.81
Height (m)	1.61
Frontal Area (m^2)	2.9141
Drag coefficient	0.18
Speed (m/s)	33.33
Air drag force (N)	349.692

Table 1.3: Hill climbing configuration

Parameter	Value
Angles in radian	0
Speed during hill climbing (m/s)	0
Force (N)	0

Table 1.4: Accelerating forces

Parameter	Value
Total weight towed	1470
Vehicle acceleration	128.947
Force (N)	0

CHAPTER 2
POWERTRAIN MODELLING

2.1 VEHICLE BODY

The ”vehicle body” block in Simulink serves as a crucial component for modeling the longitudinal motion of a two-axle vehicle, providing a platform to input various specifications and factors influencing resistive forces. This block allows for the integration of key parameters such as body mass, aerodynamic drag, road incline, and weight distribution between axles due to acceleration and road profile. By encapsulating these factors, the block enables a comprehensive simulation of the vehicle's behavior under different driving conditions.

One notable feature of the ”vehicle body” block is its ability to accommodate different configurations of wheels on each axle, reflecting the diverse designs found in real-world vehicles. This flexibility allows for accurate representation of vehicles with varying wheel arrangements, enhancing the fidelity of the simulation. Additionally, the presence of the ”Connection H (hub)” mechanical translational conserving port facilitates the modeling of horizontal motion, enabling seamless integration with other components and subsystems within the simulation environment.

In essence, the ”vehicle body” block serves as a foundational element in Simulink-based simulations of vehicle dynamics, providing a versatile and customizable platform to capture the complex interplay of factors affecting longitudinal motion. Its inclusion enhances the accuracy and realism of simulations, empowering engineers to assess and optimize vehicle performance across a range of scenarios and design parameters.

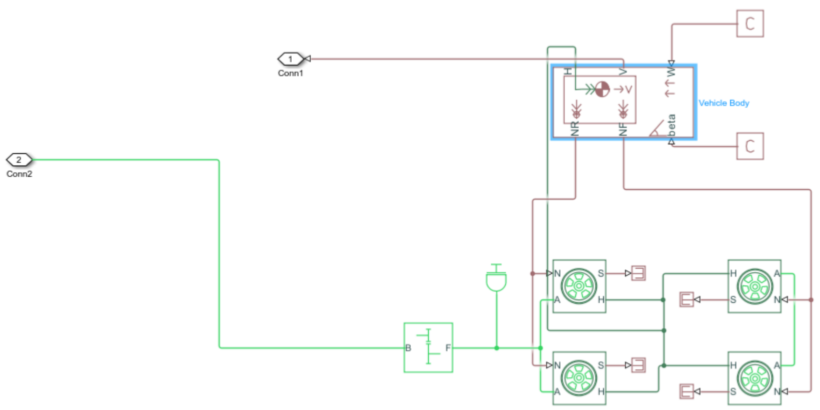

Figure 2.1: Vehicle body subsystem

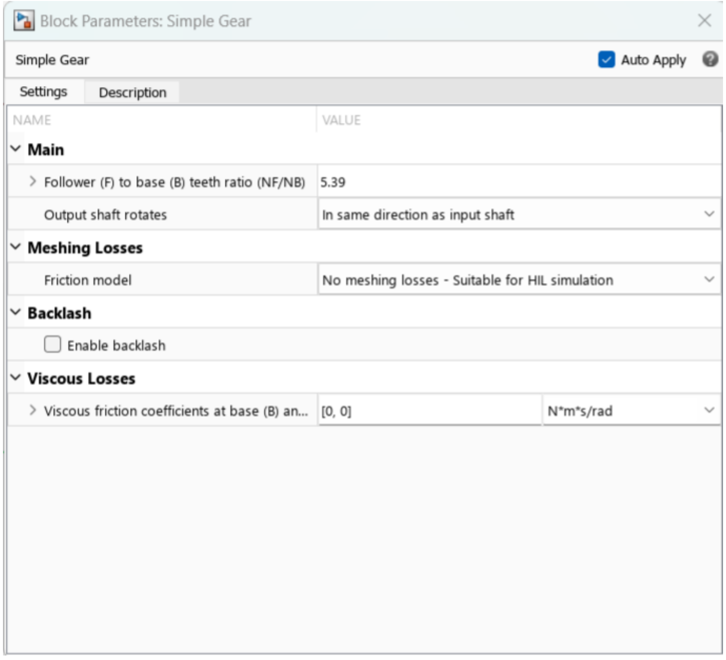

Figure 2.2: Gearbox configuration

The ”simple gear” block within the Simulink environment serves as a fundamental component for modeling the transmission system of a vehicle, allowing for the representation of fixed-ratio gears or gearboxes. Unlike more complex gear models, this block does not incorporate inertia or compliance, making it suitable for straightforward simulations where such intricacies are not necessary.

One notable feature of the ”simple gear” block is its flexibility in accounting for optional losses, including gear meshing and viscous bearing losses. By incorporating these losses into the model, engineers can more accurately simulate the efficiency of the transmission system and its impact on overall vehicle performance[4].

Furthermore, the ability to vary the gear ratio within the block enables engineers to adjust the transmission's behavior dynamically to match the desired reference velocity output. This feature is particularly useful for optimizing the vehicle's performance under different driving conditions or for accommodating changes in load or terrain.

The axle connection of the front and rear pairs of ”magic formula” tires, a common tire model used in vehicle dynamics simulations, plays a crucial role in determining the drivetrain configuration of the vehicle. When the gearbox is directly connected to the axles of the front wheels, it constitutes a Front Wheel Drive (FWD) system, whereas connecting it to the axles of the rear wheels defines a Rear Wheel Drive (RWD) system. In the case of the Tata Nexon EV, it adopts a rear-wheel-drive system, meaning that the electric motor's power is transmitted directly to the rear wheels. This configuration offers distinct advantages such as improved traction during acceleration and enhanced

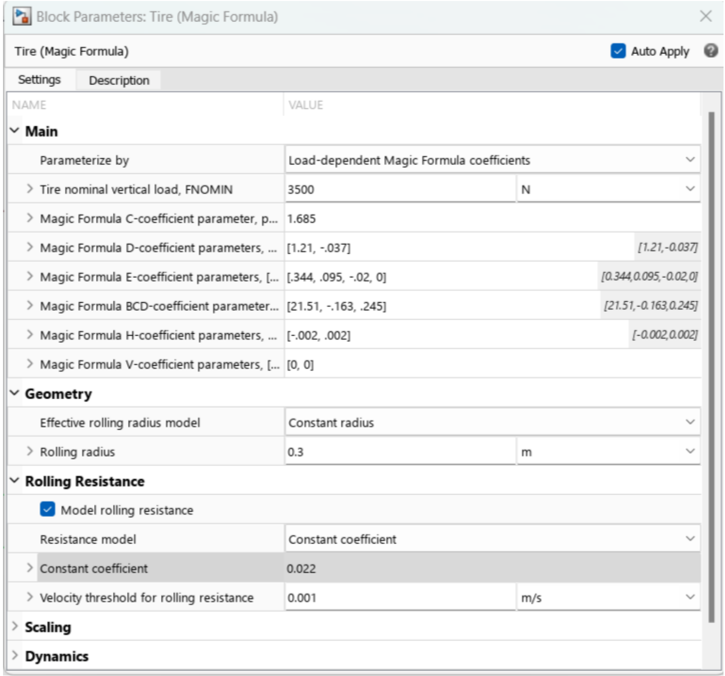

Figure 2.3: Tire configuration

stability, particularly in high-performance driving scenarios. Additionally, RWD systems often deliver a more balanced weight distribution, which can contribute to better handling dynamics. By leveraging a rear-wheel-drive setup, the Tata Nexon EV optimizes its performance and driving experience, aligning with the preferences of many drivers for a dynamic and engaging ride.

In the vehicle dynamics simulation, the output from the vehicle body subsystem, typically the vehicle velocity, serves as a pivotal input for the control system. This velocity signal is compared with the reference drive cycle to determine necessary acceleration or deceleration commands. Based on this comparison and driver inputs, such as throttle position or braking, the control system adjusts the electric motor's power output to match the desired speed profile. By continuously regulating motor power output in response to real-time driving conditions, the control system ensures smooth and efficient operation of the electric vehicle, optimizing both performance and energy consumption.

2.2 MOTOR AND MOTOR CONTROLLER

In the context of Light Electric Vehicles (LEVs), the choice of a permanent magnet DC motor is strategic due to its favorable attributes. These motors offer superior performance characterized by high efficiency, rapid response times, a straightforward structure, substantial torque output, and simplified maintenance requirements. The motor's power output is determined by the tractive power required for vehicle propulsion. Considering a typical transmission efficiency of 95 percent, the motor's power rating is

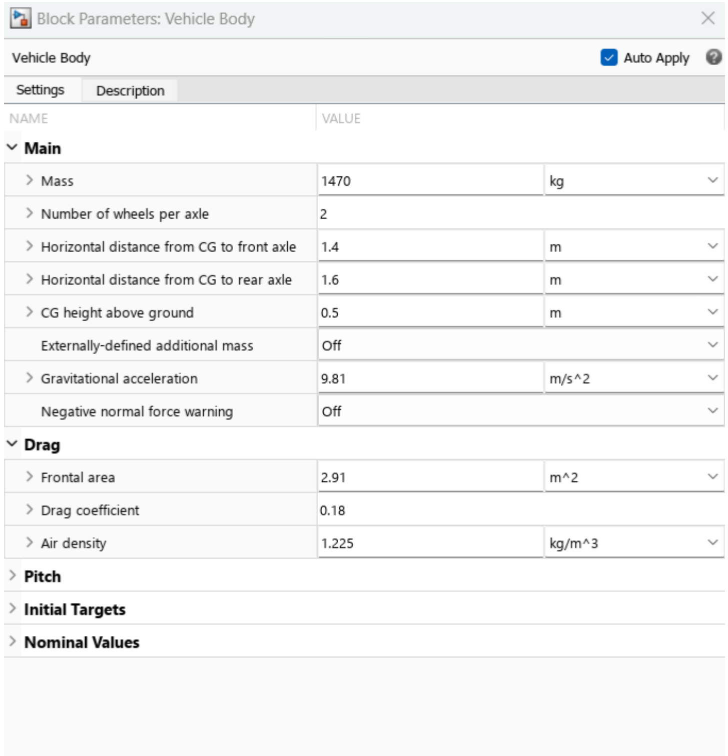

Figure 2.4: Vehicle body configuration

computed accordingly. It's noteworthy that electric motors can tolerate voltages above their rated values for short durations. In the case of LEVs, the peak motor power is around 94 kW, ensuring sufficient power for demanding acceleration scenarios. Additionally, adjustments to the motor controller and Pulse Width Modulation (PWM) source enable the vehicle to achieve its top speed as dictated by the drive cycle. This holistic approach ensures that the motor operates optimally within the constraints of the vehicle's design, performance requirements, and energy efficiency considerations, enhancing the overall performance and driving experience of the LEV

The motor controller in an electric vehicle (EV) plays a pivotal role in managing the power flow from the battery to the electric motor, ensuring efficient operation and precise control over the vehicle's propulsion. Power converter circuits form the backbone of the motor controller, employing advanced power semiconductor switches to regulate the current and voltage supplied to the motor. These power electronics circuits, operating in a switching mode, offer remarkable efficiency, often reaching levels as high as 98-99 percent. They can seamlessly switch between uni or bidirectional operation, allowing for energy flow in both directions between the battery and motor, essential for regenerative braking and energy recovery.

The four primary types of power electronics converters encompass a wide spectrum of functionalities, encompassing:

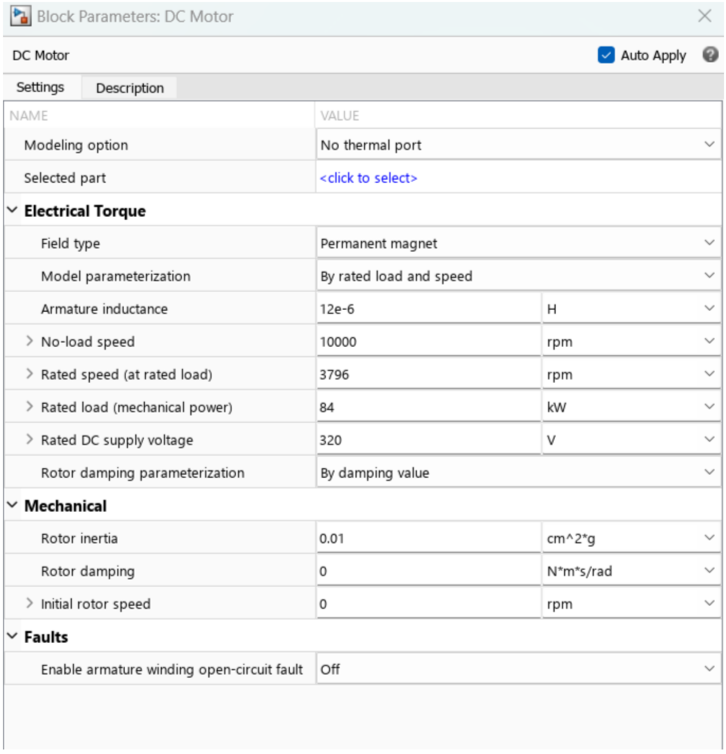

Figure 2.5: Motor configuration

1. AC to DC converters, colloquially termed controlled rectifiers
2. AC to AC converters, known as AC voltage controllers
3. DC to AC converters, commonly referred to as inverters
4. DC to DC converters, often denoted as DC choppers.

One critical aspect of power electronic circuits in EVs is their ability to facilitate regenerative braking, a key feature for enhancing energy efficiency and extending driving range. During deceleration stages, when the vehicle's kinetic energy is converted back into electrical energy, bidirectional power converters are essential. These converters enable the seamless flow of current between the electric motor and the battery, allowing energy to be recovered and stored for future use. This regenerative braking capability not only improves overall energy efficiency but also reduces wear and tear on braking systems, enhancing vehicle longevity and reliability.

In the context of motor drive systems, H-Bridge configurations are commonly employed for controlling the voltage supplied to the electric motor. To achieve precise control over motor speed and torque, the gate pulses applied to the H-Bridge must be carefully regulated according to the reference input signals. This task is typically accomplished using a controlled Pulse Width Modulation (PWM) block, which adjusts

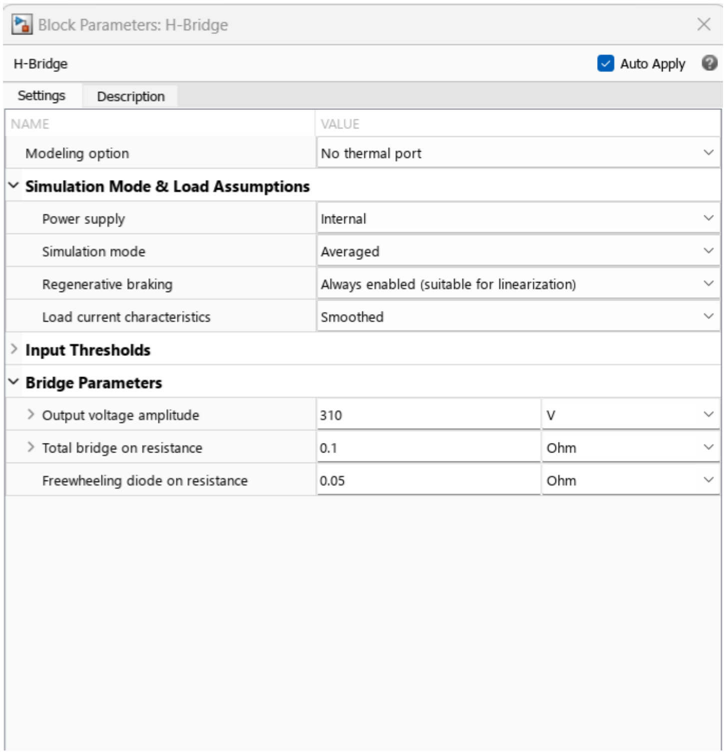

Figure 2.6: H-Bridge configuration

the pulse width and frequency of the gate signals based on user-defined parameters. By fine-tuning these parameters, such as duty cycle and modulation index, engineers can optimize motor performance and efficiency, ensuring smooth and responsive operation across a range of driving conditions.

In the integrated system of the electric vehicle (EV), the controlled voltage source receives inputs from the longitudinal controller, serving as the interface for translating acceleration and deceleration commands into precise voltage adjustments for the electric motor. The longitudinal controller, typically implemented as a Proportional-Integral-Derivative (PID) controller, plays a pivotal role in regulating vehicle speed dynamics. PID control mechanisms are adept at achieving reference tracking, ensuring that the vehicle's velocity closely follows the desired trajectory outlined by the drive cycle.

The drive cycle encapsulates the vehicle's velocity profile at various time intervals, serving as a benchmark for desired performance. By leveraging a PID controller within the longitudinal driver block, the system aims to establish control over the vehicle's output velocity, effectively tracking the input reference velocity provided by the drive cycle. The longitudinal driver block functions as a parametric longitudinal speed tracking controller, generating normalized acceleration and braking commands based on the discrepancy between the reference and feedback velocities. Through iterative adjustments, the controller fine-tunes these commands to ensure smooth and responsive ve-

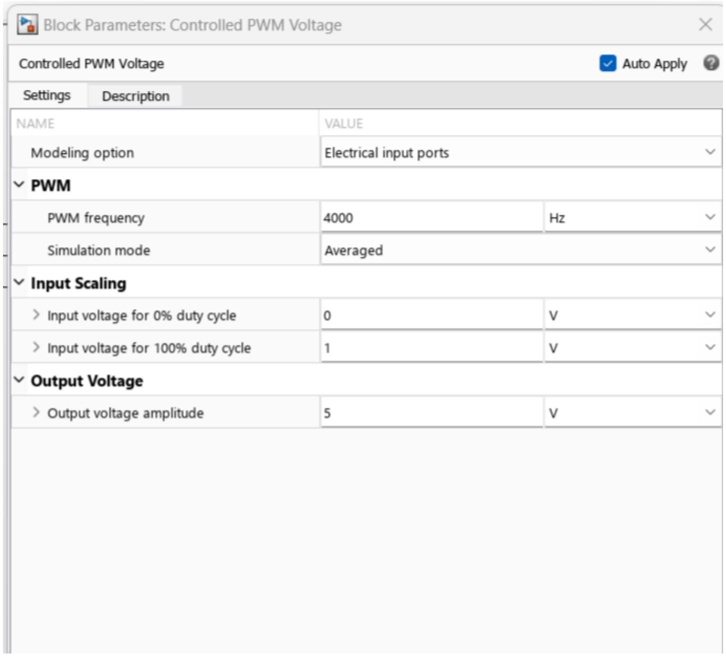

Figure 2.7: PWM configuration

hicle acceleration and deceleration, optimizing both performance and energy efficiency throughout the driving experience [5].

The Controlled PWM Block serves as a pivotal component within the electric vehicle's (EV) powertrain, responsible for generating pulse-width modulated (PWM) voltage signals across the PWM and REF ports. These signals are instrumental in controlling the operation of the H-Bridge, regulating the voltage supplied to the electric motor with precision. The parameters of the PWM block play a critical role in optimizing the performance and efficiency of the motor drive system. One such parameter is the switching frequency, which dictates the rate at which the pulses are applied to open and close the H-Bridge. This frequency determines the speed at which the power semiconductor switches operate, influencing factors such as electromagnetic interference (EMI), switching losses, and overall system efficiency. By carefully adjusting the switching frequency, engineers can fine-tune the motor drive system's operation, balancing performance, efficiency, and electromagnetic compatibility (EMC) considerations to meet the stringent requirements of modern electric vehicle applications.

2.3 DRIVE CONTROLLERS

Drive controllers are essential components within the powertrain of electric vehicles (EVs), responsible for regulating the vehicle's longitudinal motion, managing grade transitions, and ensuring precise control over acceleration and deceleration. These controllers play a critical role in optimizing vehicle performance, energy efficiency, and overall driving experience

1. Longitudinal Drive Control: The longitudinal drive controller governs the vehicle's forward and backward motion along its longitudinal axis. It receives inputs such as the reference velocity, representing the desired speed profile based on driving conditions or driver commands, and the feedback velocity, obtained from sensors monitoring the actual vehicle speed. By comparing these inputs, the longitudinal drive controller generates commands to adjust motor power output, maintaining the vehicle's speed in accordance with the reference velocity.

2. Grade Transition Control: Grade transition control is responsible for managing changes in road gradient or slope, ensuring smooth and efficient operation of the vehicle during uphill climbs or downhill descents. By monitoring inputs such as road inclination or grade angle, the controller adjusts motor power output to compensate for changes in gravitational forces, optimizing energy usage and vehicle performance on varying terrain.

3. Acceleration and Deceleration Command Generation: The drive controller generates commands for accelerating and decelerating the vehicle based on the deviation between the reference and feedback velocities. When the vehicle's speed deviates from the desired velocity profile, the controller computes the required acceleration or deceleration commands to bring the vehicle back to the target speed. These commands are then translated into adjustments to the motor's power output via the powertrain's electronic control unit (ECU) or motor controller.

4. Reference Velocity: The reference velocity represents the desired speed profile that the vehicle should follow based on various factors such as driver inputs, road conditions, and safety considerations. It serves as the target speed setpoint for the vehicle's longitudinal motion. The reference velocity is typically provided by the vehicle's onboard systems or derived from driver commands. It forms the basis for the drive controller to generate appropriate commands for acceleration or deceleration, ensuring that the vehicle maintains its speed in accordance with the desired velocity profile.

5. Feedback Velocity: The feedback velocity, on the other hand, is the actual speed of the vehicle obtained from sensors or monitoring systems integrated into the EV. These sensors measure the rotational speed of the vehicle's wheels or other relevant parameters to provide real-time feedback on the vehicle's velocity. The feedback velocity is crucial for the drive controller, enabling continuous comparison between the actual vehicle speed and the desired reference velocity. Any disparities between these velocities trigger the drive controller to adjust motor power output, ensuring the vehicle accurately maintains the desired speed profile.

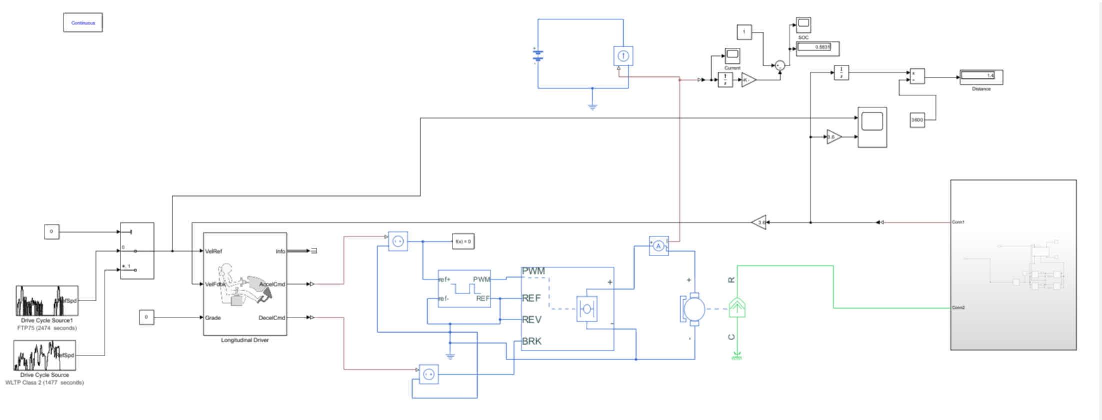

Figure 2.8: Powertrain of EV (Tata Nexon EV)

2.4 DRIVE CYCLE AND BATTERY INPUT

To run the powertrain of an electric vehicle (EV) with a permanent magnet DC (PMDC) motor using an H-bridge power converter, the drive cycle and battery input play crucial roles in determining the performance and efficiency of the system.

1. Drive Cycle: The drive cycle defines the vehicle's speed and torque requirements over time. It includes periods of acceleration, cruising, and deceleration. The power converter must be able to adjust the voltage and current supplied to the motor to meet these varying demands efficiently[6].

2. Battery Input: The battery provides the DC voltage to the power converter. The power converter (H-bridge) then converts this DC voltage into AC voltage to drive the PMDC motor. The battery's capacity and voltage level determine the vehicle's range and performance. The power converter must efficiently convert the battery's DC voltage into the required AC voltage for the motor, taking into account the battery's state of charge and its voltage limitations[7].

To effectively run the powertrain of an EV with a PMDC motor, the power converter must be able to modulate the voltage and current supplied to the motor based on the drive cycle's demands, while also ensuring that the battery is not overcharged or discharged beyond its limits. Advanced control algorithms can be used to optimize the power converter's operation for different drive cycles, maximizing efficiency and performance.

The drive cycle of WLDC Class 2 and FTP75 is utilized to simulate real-world driving conditions. This approach allows for the analysis of the powertrain's performance under different scenarios, including acceleration, cruising, and deceleration phases.

The model provides valuable insights into the powertrain's behavior by capturing

Figure 2.9: WLDC Class 2 Drive Cycle

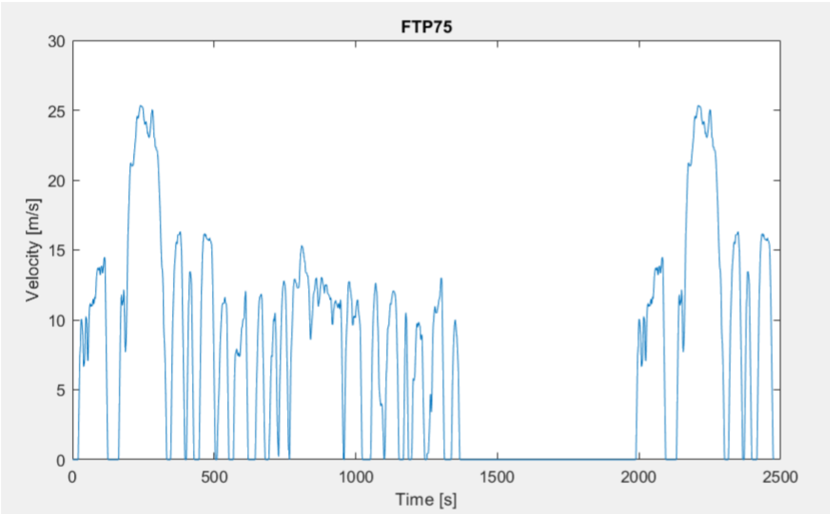

Figure 2.10: FTP75 Drive Cycle

key parameters such as feedback velocity, current waveform during runtime, and State of Charge of the battery. These parameters are essential for evaluating the system's efficiency, performance, and overall effectiveness.

The model accounts for regenerative braking, which boosts energy efficiency by recovering energy during braking to charge the battery. This feature allows for a detailed analysis of the powertrain's energy management system.

Matching the feedback velocity (actual velocity) with the drive cycle (reference velocity) is indeed an important validation step to assess the accuracy of the model. If the actual velocity closely matches the reference velocity throughout the simulation, it indicates that the model accurately represents the behavior of the powertrain under the given drive cycle[8].

CHAPTER 3
RESULTS AND DISCUSSIONS

The simulation results of the Tata Nexon EV configured model, using WLDC Class 2 and FTP75 drive cycles, show the following outputs:

1. Feedback Velocity: The model provides the feedback velocity, which represents the actual velocity of the vehicle during the simulation. This is compared against the reference velocity from the drive cycles to evaluate the model's accuracy.

2. Current: The simulation also provides the current waveform during runtime. This waveform indicates the current flowing through the powertrain components, such as the motor and power converter, under different driving conditions.

3. State of Charge (SoC): The SoC of the battery is another output of the simulation. It shows the level of charge remaining in the battery at any given time during the drive cycle.

These outputs are essential for analyzing and optimizing the performance of the powertrain, including the motor, power converter, and battery, in the Tata Nexon EV under various driving conditions.

3.1 FEEDBACK VELOCITY

It is observed that the feedback velocity (Vel FdbK) closely matches the reference velocity given by the respective drive cycles, indicating an accurate simulation of the vehicle's actual speed. Vel FdbK is obtained from the vehicle body subsystem and represents the actual velocity of the vehicle.

In real-world driving scenarios, the driver compares the reference speed (from the drive cycle) with the actual speed (feedback velocity). If there is a positive error (i.e., the reference speed is greater than the actual speed), the driver will press the accelerator to increase the speed. Conversely, if the actual speed is greater than the reference speed, the driver will apply the brakes to reduce the speed.

The longitudinal driver generates a physical signal based on these comparisons, which needs to be converted to an electrical signal for further processing. To achieve this conversion, a ps - Simulink converter is used, allowing the physical signal to be processed in Simulink. This enables the simulation to accurately reflect the driver's actions and their impact on the vehicle’s speed.

3.1.1 WLDC Class 2 Drive Cycle

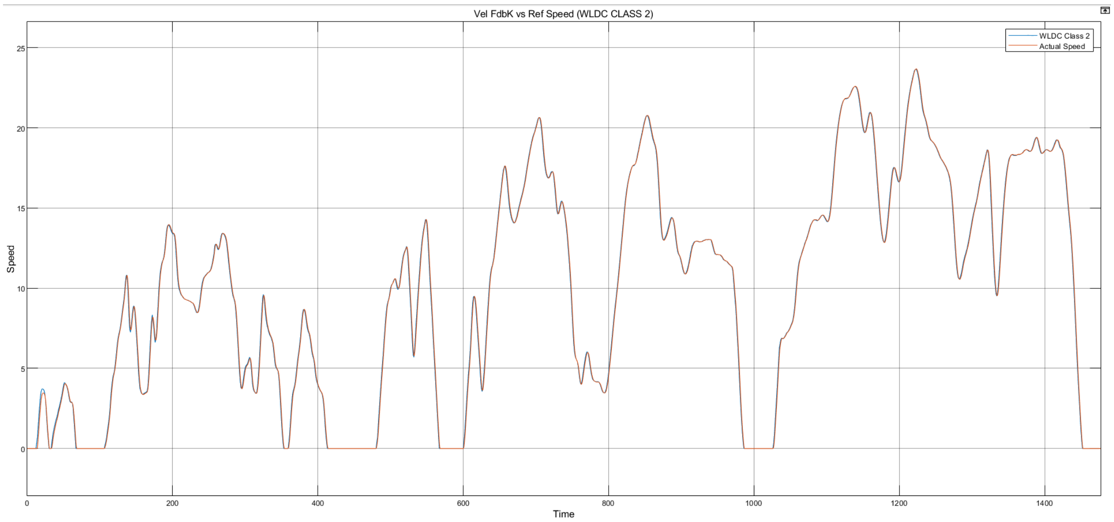

Figure 3.1: Speed Comparision (WLDC CLASS 2)

3.1.2 FTP75

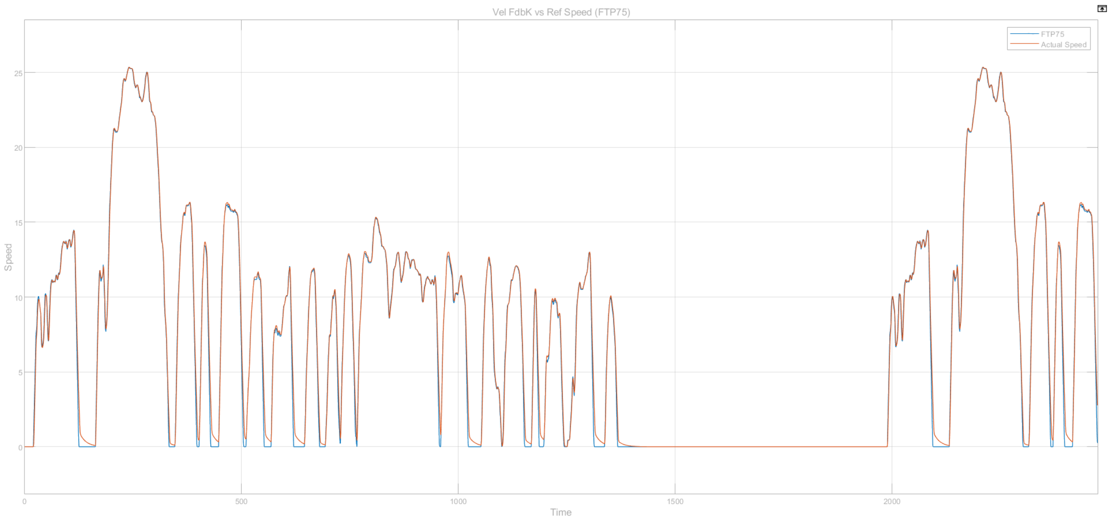

Figure 3.2: Speed Comparision (FTP75)

3.2 CURRENT WAVEFORM

The current waveform obtained in the powertrain during standard drive cycles like WLDC (World Harmonized Light Duty Vehicle Test Cycle) and FTP75 (Federal Test Procedure 75) can vary based on the specific vehicle and powertrain configuration. The waveform may exhibit peaks during acceleration and regenerative braking events, and relatively stable current levels during cruising.

3.2.1 WLDC Class 2 Drive Cycle

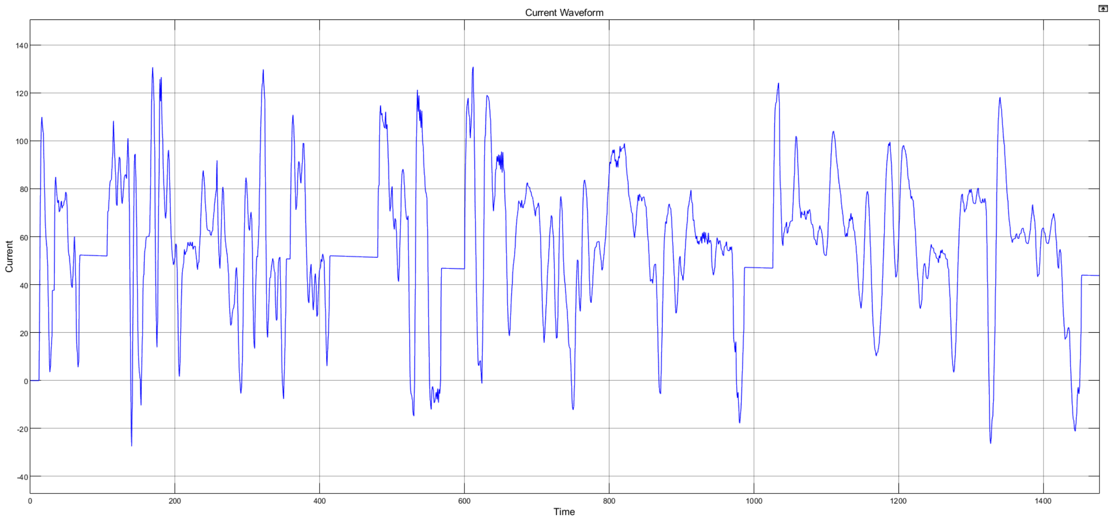

Figure 3.3: Current - WLDC Class 2

3.2.2 FTP75

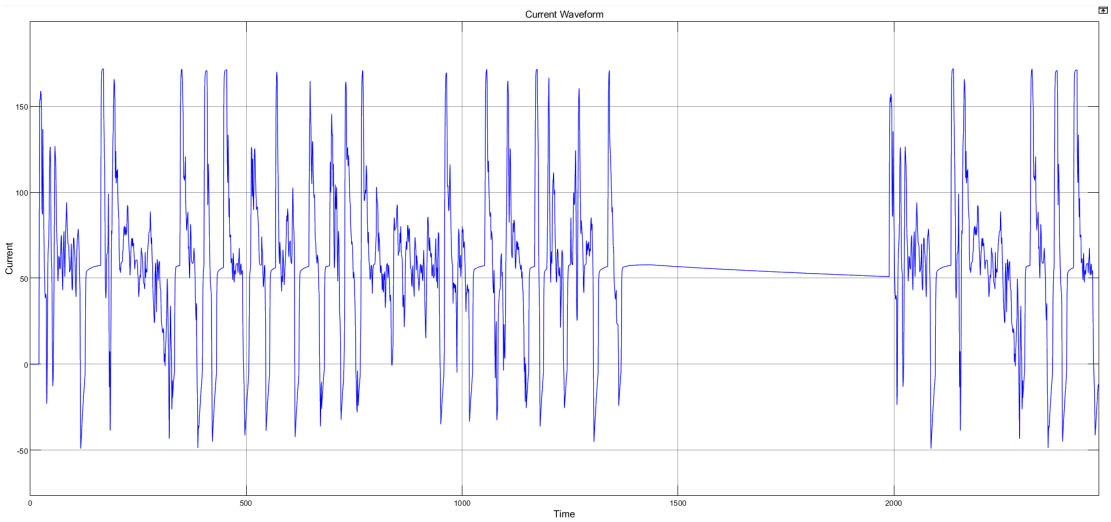

Figure 3.4: Current Waveform

3.3 STATE OF CHARGE (SOC)

The SoC behavior during discharging with regenerative braking reflects the dynamic nature of energy flow in an electric vehicle powertrain.

3.3.1 WLDC Class 2 Drive Cycle

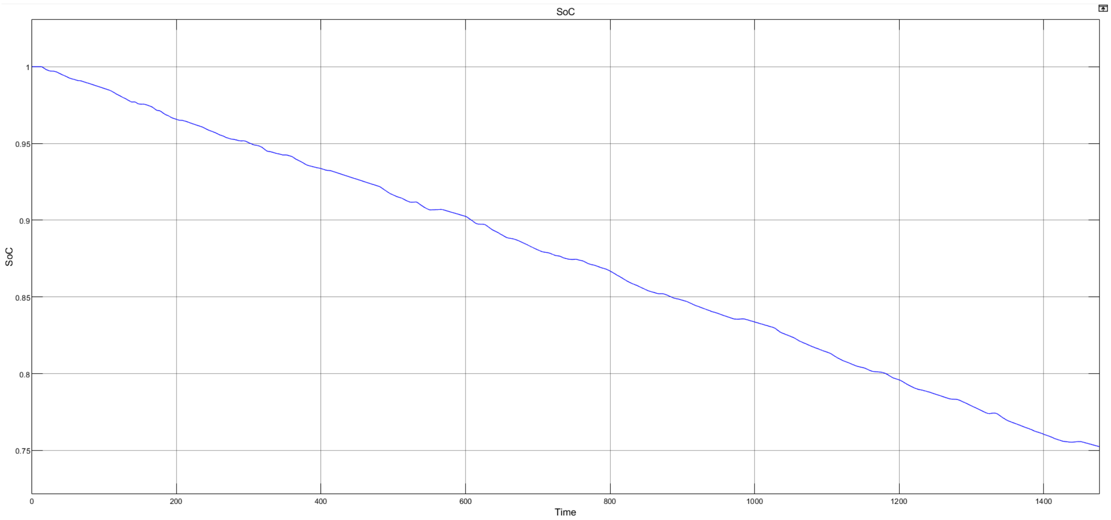

Figure 3.5: SoC - WLDC

3.3.2 FTP75

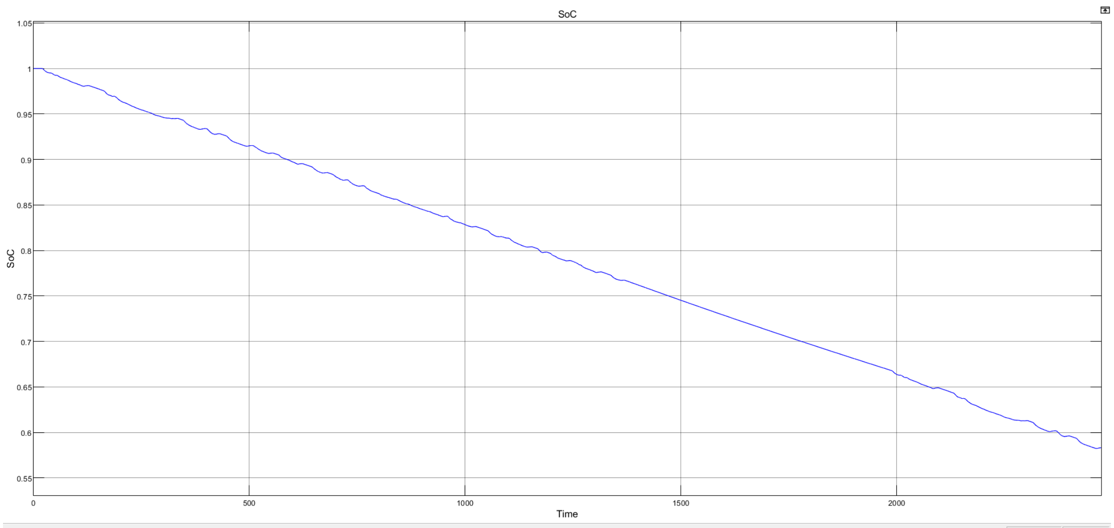

Figure 3.6: SoC - FTP75

CHAPTER 4
CONCLUSIONS AND FUTURE SCOPE

In developing an electric vehicle (EV) powertrain inspired by the Tata Nexon EV, the comparison between feedback velocity and reference velocity revealed a close match, validating the accuracy of the model. The analysis of the current waveform during runtime provided insights into the powertrain's dynamic behavior, with peaks indicating high power demands during acceleration and regenerative braking phases. Additionally, monitoring the State of Charge (SoC) during discharging with regenerative braking highlighted the effectiveness of this system in replenishing the battery's charge.

For future enhancements, integrating a Battery Management System (BMS) with a Kalman filter for SoC estimation offers improved accuracy and efficiency in managing the battery's charge. The Kalman filter's ability to account for various factors such as voltage, current, and temperature will enhance SoC estimation, leading to better energy management and prolonged battery life.

Implementing Field-Programmable Gate Array (FPGA) technology in the powertrain will enable real-time processing of data, enhancing control algorithms and overall performance. FPGA's flexibility allows for customization, optimizing the powertrain's operation under different driving conditions. Furthermore, integrating self-charging capabilities, such as regenerative braking and other innovative methods, will enhance the vehicle's energy efficiency and range, making it more sustainable and practical for daily use.

In conclusion, the development and analysis of the EV powertrain have provided valuable insights into its performance and efficiency. Future integration of advanced technologies like BMS with a Kalman filter, FPGA implementation, and self-charging capabilities will further enhance the powertrain's efficiency and sustainability, advancing the adoption of EVs as a cleaner and more viable mode of transportation. Continued research and innovation in these areas will be crucial in accelerating the transition to a greener automotive industry.

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