# MODELING AND SIMULATION OF ELECTRIC AND HYBRID ELECTRIC VEHICLE POWERTRAIN

## M.Tech. Thesis

By

**VIVEK PALIWAL**

**(2002106003)**

**DEPARTMENT OF CEVITS**

**INDIAN INSTITUTE OF TECHNOLOGY INDORE**

**MAY 2023**

# MODELING AND SIMULATION OF ELECTRIC AND HYBRID ELECTRIC VEHICLE POWERTRAIN

**A THESIS**

*Submitted in partial fulfillment of the requirements for the award of the degree*

***of***

**Master of Technology**

*by*

**VIVEK PALIWAL**

**DEPARTMENT OF CEVITS**

**INDIAN INSTITUTE OF TECHNOLOGY INDORE**

**MAY 2023**

# INDIAN INSTITUTE OF TECHNOLOGY INDORE

## CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **MODELING AND SIMULATION OF EV AND HEV POWERTRAIN** in the partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY** and submitted in the **DEPARTMENT OF CEVITS, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from August 2021 to May 2023 under the supervision of **Dr. Devendra Deshmukh, Professor, Department of Mechanical Engineering, Indian Institute of Technology**.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

Vivek
01/06/2023

**(Vivek Paliwal)**

---

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

**(Dr. Devendra Deshmukh)**

---

**Mr. Vivek Paliwal** has successfully given his M.Tech. Oral Examination held on **May 18, 2023.**

Signature(s) of Supervisor(s) of M.Tech. thesis
Date: Prof. Devendra Deshmukh 2/6/2023

Convener, DPGC
Date: Dr. Sunil Kumar 05/06/2023

Signature of PSPC Member #1
(Dr. Amod Umarikar)
Date: 03/06/2023

Signature of PSPC Member #2
(Dr. Indrasen Singh)
Date: 05/06/2023

---

# ACKNOWLEDGEMENT

My deep gratitude goes first to my supervisors, **Dr. Devendra Deshmukh**, who expertly guided me throughout my two years of Master of Technology. I was fortunate to have advisors who offered me the constant motivation and productive support that preceded this work to attain this form. A special thanks to my PSPC members, Dr. Amod Umarikar and Dr. Indrasen Singh for their continuous inputs for the advancement of this project.

A very special thanks to Devashish Chorey (Ph.D. scholar), Mr. Vishal Jagdale (Ph.D. scholar), and Mr. Arpit Joglekar (Ph.D. scholar) for their moral support and supportive environment for the completion of the project. Thanks also goes to Mr. OP. Mishra, Mr. Maitreya Jain, Mr. Prashant Mall, and my other batch-mates for their moral support throughout this journey. I am also thankful to Mr. Ashwin Wagh , Dept manager, Spray and Combustion Lab, IIT Indore.

I cannot end my words without expressing my heartfelt thanks and admiration for my dear parents' blessings and efforts to maintain my morale throughout my project. I would want to express my sincere gratitude to everyone. who has assisted me in any way, whether directly or indirectly, during this project.

With Regards,

**Vivek Paliwal**

***Dedicated***

***to***

***My beloved***

***Mom and Dad***

# Abstract

These days, there is a higher demand for electric and hybrid vehicles due to the rising cost of fuel and its negative impact on the environment. To fulfil the higher performance demands of the EV and HEV, it is crucial to comprehend the behavior of the entire electric power train. We model and simulate the EV and HEV powertrain components in MATLAB to increase fuel economy and emissions reduction. When it comes to EV and HEV architecture, we use a DC Motor and BLDC Motor by adapting the physical specifications of the TATA NEXON EV. Watch how the vehicle performs differently while utilising different electric motors and control algorithms. We use libraries like Simscape, Powertrain Blockset, Control System, Simulink, and Vehicle Dynamic Blockset to model various drivetrain components in MATLAB and examine performance. The Modified Indian Drive Cycle (MIDC), which is used in India to assess and compare the performance of automobiles, should be utilized to test the vehicle.

# Contents

Chapter 1 Introduction ..................................................................... 20

1.1 Overview........................................................................................ 20

1.2 Electric and Hybrid Electric Vehicles Powertrain .............................. 21

1.2.1 Battery Electric Vehicles (BEV) ................................................. 21

1.2.2 Hybrid Electric Vehicles (HEV) .................................................... 22

1.2.3 MATLAB Simulation for EV and HEV ...................................... 23

1.3 Significance and objectives of the study ............................................ 24

Chapter 2 Literature review.................................................................... 26

Chapter 3 Electric and Hybrid Electric Vehicle Powertrain Component and Architectures.......................................................................................... 30

3.1 Introduction.................................................................................... 30

3.2 Selection of EV and HEV Battery...................................................... 31

3.3 Selection of Traction Motor for HEV and EV.................................... 32

3.4 Selection of Transmission for EV and HEV....................................... 33

3.5 Regenerative Braking in HEV and EV............................................... 34

3.6 Power Electronics in EV and HEV .................................................... 35

3.7 Vehicle Weight and Performance ...................................................... 35

3.8 EV Architecture and Design ............................................................. 36

3.9 HEV Architecture and Design .......................................................... 37

3.9.1 Series and Parallel Hybrid.......................................................... 37

3.9.2 Series-Parallel Hybrid................................................................. 39

3.9.3 Series–Parallel 2 × 2 Hybrid ...................................................... 40

Chapter 4 Component Modelling in Simulink and Simscape ........................ 41

4.1 Physical Network Approach To Modelling Using Simscape ............... 42

4.2 Introduction To Vehicle Dynamics And Simscape............................. 43

4.3 Modelling of Energy Source.............................................................. 44

4.4Modelling of Power Convertor Device ............................................... 47

4.4.1 PID Controller: ........................................................................... 47

4.4.2 Invertor........................................................................................ 48

4.5 Vehicle Body.................................................................................... 51

4.6 Equations....................................................................................... 52

4.7 Model ........................................................................ 53
4.8 Vehicle Simulation In MATLAB for Different Architecture ............... 54
4.8.1 Series Hybrid Powertrain ................................................ 54
4.8.2 Parallel Hybrid Drivetrain ............................................... 58
4.8.3 TATA NEXON Electric Vehicle based on DC MOTOR .............. 62
4.8.4 MATLAB MODEL of TATA NEXON Based On BLDC Motor.. 67
CHAPTER 5 Conclusion and future scope ......................................... 72
5.1. Conclusion ................................................................ 72
5.2. Future scope ............................................................. 73

# LIST OF FIGURES

Fig. 3.1: The main electrical parts of an EV system

Fig. 3.2: Series HEV powertrain

Fig. 3.3: Parallel HEV powertrain

Fig. 3.4: Parallel and Series combination HEV

Fig. 3.5: 2 x 2 vehicle architecture with series parallel

Fig. 4.1: Simscape library in MATLAB

Fig. 4.2: Libraries that are part of the foundation library Simscape

Fig. 4.3: Driveline library options offered by Simscape

Fig. 4.4: Basic design of cell

Fig. 4.5: Design of 48V Battery Pack

Fig. 4.6: Parameter to Control Li-ion Battery

Fig. 4.7: MATLAB Block PID Controller

Fig. 4.8: Parameter to tune PID controller

Fig. 4.9: Implementation of 3-phase Invertor Using 6 IGBT switch

Fig. 4.10: Design of DC-DC Convertor MATLAB

Fig. 4.11: Parameter selection for DC-DC convertor

Fig. 4.12: **Vehicle Dynamics and Motion for Vehicle**

Fig. 4.13: MATLAB Model of complete vehicle body

Fig. 4.14: Represent Parameter of Vehicle Body

Fig. 4.15: Model of Series Hybrid Powertrain in MATLAB

Fig. 4.16: Vehicle following MIDC Speed profile

Fig. 4.17: Change of speed using fixed gear having gear ratio 4

Fig. 4.18: Distance travelled by series hybrid vehicle over one MIDC cycle

Fig. 4.19: Engine and Motor shaft speed in series hybrid vehicle over one MIDC cycle

Fig. 4.20: Battery Charge (Amphere-hour) over one MIDC cycle

Fig. 4.21: Battery Electrical Losses in series hybrid vehicle over one MIDC cycle

Fig. 4.22: Engine Fuel Consumption in series hybrid vehicle over one MIDC cycle

Fig. 4.23: Modelling parallel hybrid drivetrain over in MATLAB

Fig. 4.24: Vehicle following MIDC Speed profile

Fig. 4.25: Battery Electrical Losses in parallel hybrid vehicle over one MIDC cycle

Fig. 4.26: Engine Fuel Consumption in series hybrid vehicle over one MIDC cycle

Fig. 4.27: Battery Charge (Amphere-hour) over one MIDC cycle

Fig. 4.28: Battery and Engine Power over one MIDC cycle in parallel drivetrain

Fig. 4.29: MATLAB Model of EV based on TATA NEXON

Fig. 4.30: Vehicle following MIDC Speed profile

Fig. 4.31: Li-Ion Battery SOC, Current, Voltage Over a Cycle

Fig. 4.32: Variation of Normal force on front and rear wheel

Fig. 4.33: Variation of Voltage and Current inside the DC Motor

Fig. 4.34: Simple gear with gear ratio 4

Fig. 4.35: Acceleration/Decceleration (m/s2)

Fig. 4.36: Closed loop control BLDC vehicle (TATA NEXON)

Fig. 4.37: Implimentation of BLDC Motor With Controller In MATLAB

Fig. 4.38: Hall Sensor Logic Design in MATLAB

Fig. 4.39: Vehicle body in MATLAB Model using simscape

Fig. 4.40: Commutaion logic Model in MATLAB

Fig. 4.41: Desire VS Actual Speed Comparison on MIDC Cycle

Fig. 4.42: Modulated DC voltage by BUCK-BOOST Convertor

Fig. 4.43: Three-Phase Current and Voltage by Controller

# LIST OF TABLES

Table 4.1: In several areas, through and across variables

Table 4.2: Constant used in vehicle dynamic equation

Table 4.3: Vehicle parameter require for electric vehicle powertrain simulation

Table 5.1: Simulation Result of TATA Nexon On Different Motor

Table 5.2: Voltage selection for powertrain among different vehicles

Table 5.3: Requirement of Traction motor with Speed

# ACRONYMS

| | |
|---|---|
| **HEV** | Hybrid Electric Vehicle |
| **MIDC** | Modified Indian Drive Cycle |
| **VCU** | Vehicle Control Unit |
| **GVW** | Gross Vehicle Weight |
| **SVM** | Support vector machine |
| **SOC** | State Of Charge |
| **SOH** | State Of Health |
| **BEV** | Battery Electric Vehicle |
| **BMS** | Battery Management System |

# Chapter 1 Introduction

## 1.1 Overview

Electric and Hybrid Electric Vehicle (HEV) powertrains are becoming increasingly popular as a way to reduce the reliance on traditional combustion engines and move towards more sustainable transportation.

MATLAB is a powerful tool for modeling and simulating these powertrains, allowing engineers and researchers to design, optimize, and test their performance.

The basic components of an electric powertrain include the battery, electric motor, and power electronics. The battery stores electrical energy that is used to power the electric motor, which in turn drives the vehicle's wheels. Power electronics control the flow of electrical energy between the battery and the motor.

HEV powertrains also include an internal combustion engine, which can be used to supplement the electric motor or recharge the battery. The engine is usually connected to a generator, which produces electricity to power the electric motor or charge the battery.

MATLAB provides a number of tools for modeling and simulating electric and HEV powertrains. The Simulink environment allows engineers to build models of the powertrain components and simulate their behavior under different operating conditions. The Simscape library provides models for simulating the physical behavior of components such as batteries, electric motors, and power electronics.

Using these tools, engineers can analyze the performance of the powertrain under different conditions, such as acceleration, braking, and regenerative braking. They can also optimize the design of the powertrain components to improve efficiency and reduce emissions.

## 1.2 Electric and Hybrid Electric Vehicles Powertrain

Hybrid electric vehicles (HEVs) and electric vehicles (EVs) have different powertrains compared to traditional gasoline-powered vehicles.
An electric vehicle is powered by an electric motor and a battery. Electrical energy in the battery is transformed into mechanical energy by the electric motor., which powers the wheels. The battery is recharged by plugging the vehicle into an electrical outlet, using regenerative braking, or in some cases, through a hydrogen fuel cell.

A hybrid electric vehicle, on the other hand, has both an internal combustion engine (ICE) and an electric motor. The two power sources work together to power the vehicle. In a parallel hybrid, both the electric motor and ICE can power the wheels independently or together. In a series hybrid, the ICE is used only to generate electricity to power the electric motor, which then powers the wheels.

In both EVs and HEVs, the powertrain is controlled by an electronic control unit (ECU), which manages the flow of power between the battery, electric motor, and ICE. The ECU also manages other systems, such as regenerative braking and climate control, to optimize the vehicle's efficiency and performance.

Overall, electric and hybrid electric powertrains offer several advantages over traditional gasoline-powered vehicles, including lower emissions, reduced dependence on fossil fuels, and improved fuel efficiency.

### 1.2.1 Battery Electric Vehicles (BEV)

BEVs store electrical energy in rechargeable battery packs that are usually located under the car's floor or in the trunk. The batteries are charged using an external power source, such as a charging station or a standard electrical outlet.

Depending on the size of the battery and the type of charging, it can take anywhere from a few hours to overnight to fully charge a BEV.

BEVs are considered to be a cleaner and more environmentally friendly alternative to traditional gasoline-powered cars because they produce zero tailpipe emissions. However, the production of electricity used to charge the batteries may produce emissions, depending on the source of the electricity. In addition, the production of the batteries themselves requires a significant amount of energy and resources, which can have environmental impacts.

BEVs have several advantages over traditional gasoline-powered cars. They are generally more energy-efficient and have lower operating costs because electricity is cheaper than gasoline. They also require less maintenance because they have fewer moving parts than traditional cars. However, their range is typically lower than gasoline-powered cars, and they require charging infrastructure to be built out in order to become a more practical option for many people.

Despite some challenges, BEVs are becoming increasingly popular and are seen as a key part of the transition to a more sustainable transportation system. Many countries and cities around the world are implementing policies to encourage the adoption of BEVs, such as tax incentives, subsidies, and the installation of public charging stations.

### 1.2.2 Hybrid Electric Vehicles (HEV)

An automobile that is powered by both an internal combustion engine (ICE) and an electric motor is referred to as a hybrid electric vehicle (HEV). HEVs are designed to be more fuel-efficient and produce fewer emissions than traditional gasoline-powered cars.

HEVs come in two types: parallel and series. In a parallel HEV, both the ICE and the wheels can be powered by the electric motor., while in a series HEV, the ICE is used to generate electricity to power the electric motor, which in turn powers the wheels.

HEVs store electrical energy in a battery pack, which is charged by the ICE or by regenerative braking. Regenerative braking is a technique that utilises energy that would otherwise be lost during braking to recharge the battery.

HEVs have several advantages over traditional gasoline-powered cars. They are more fuel-efficient, producing fewer emissions and using less gasoline. They also have lower operating costs because they require less maintenance than traditional cars. However, they are more expensive than traditional cars due to the added cost of the electric motor and battery pack.

HEVs are a good option for people who want to reduce their fuel consumption and emissions but are not ready to switch to a fully electric vehicle. They are also a good choice for people who frequently drive long distances and need the flexibility of a gasoline-powered engine.

Despite some challenges, HEVs are becoming increasingly popular and are seen as a key part of the transition to a more sustainable transportation system. Many car manufacturers are investing in HEV technology, and governments around the world are implementing policies to encourage the adoption of HEVs, such as tax incentives and subsidies.

### 1.2.3 MATLAB Simulation for EV and HEV

Modelling and simulation are critical tools for the design and analysis of hybrid electric vehicles (HEVs) and electric vehicles (EVs). MATLAB is best for numerical computing, a high-level programming language and environment, is commonly used for modelling and simulation of EVs and HEVs.

In EVs and HEVs, the electric motor is the primary propulsion source, and the batteries or other energy storage devices provide the power required for the motor. The performance and efficiency of these vehicles depend on various factors such as motor characteristics, battery capacity, vehicle weight, and driving conditions. Mathematical models can be developed to represent the behavior of each component and their interactions, allowing for the prediction of vehicle performance under different scenarios.

MATLAB provides a range of tools for modelling and simulating EVs and HEVs. The Simulink tool is particularly useful for creating block diagrams that represent the behavior of individual components and their interactions. These block diagrams can be used to model the system's behaviour as a whole under different conditions and to optimize the system's performance.

There are several benefits to using MATLAB for EV and HEV modelling and simulation. Firstly, MATLAB offers a user-friendly environment for creating and testing mathematical models. Additionally, MATLAB has a large library of built-in functions that can be used for numerical analysis and optimization. Finally, MATLAB allows for easy integration with other software tools and data sources, making it a powerful tool for system-level analysis.

In summary, MATLAB is an essential tool for the modelling and simulation of EVs and HEVs. Its range of tools and capabilities allows for the creation of accurate and effective models that can be used to optimize the performance and efficiency of these vehicles.

## 1.3 Significance and objectives of the study

The objective of studying MATLAB simulation models for Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs) is to understand and analyze the behavior and performance of these vehicles under different driving conditions and powertrain configurations. MATLAB simulation models are used to design and optimize the control strategies and energy management systems of EVs and

HEVs, which are crucial for improving their efficiency, range, and overall performance.

Specifically, the study of MATLAB simulation models for EVs and HEVs can help:

- Evaluate the impact of different powertrain configurations, including battery sizing, motor sizing, and control strategies, on vehicle performance, such as acceleration, top speed, range, and energy consumption.
- Analyze the effects of different driving conditions, such as road grade, traffic, and weather, on the vehicle's energy consumption and range.
- Optimize the energy management system, including the battery management system, power electronics, and thermal management, to enhance the vehicle's efficiency and reliability.
- Develop and test different control strategies, such as regenerative braking, torque vectoring, and power split control, to enhance the performance of the vehicle, stability, and safety.
- Compare the performance and efficiency of different EV and HEV models, and identify the trade-offs between different powertrain configurations and vehicle designs.

Overall, the study of MATLAB simulation models for EVs and HEVs is essential for designing, testing, and optimizing these vehicles' powertrains, energy management systems, and control strategies to enhance their performance, efficiency, and sustainability.

# Chapter 2 Literature review

Electric and hybrid electric vehicles have been gaining increasing popularity due to the need for sustainable transportation solutions. The powertrain of these vehicles is a key factor in their performance and efficiency, and its design and optimization can be facilitated by computer simulations. MATLAB is a commonly used tool for simulating powertrain systems, allowing engineers and researchers to investigate different configurations and control strategies. This literature review will summarize recent research on the use of MATLAB simulations for EV and HEV powertrain analysis and design.

1. **Simulation of EV Powertrain with MATLAB/Simulink: A Comprehensive Review by Wang et al. (2019) :**
   This review paper provides an overview of the different components of an EV powertrain and their modeling and simulation in MATLAB/Simulink. The paper also discusses the challenges and opportunities in EV powertrain design and optimization, and highlights the importance of accurate modeling and simulation for performance evaluation.

2. **Comparison of Different Battery Models for EV Powertrain Simulation using MATLAB/Simulink by Ghorbani et al. (2021):** This study compares the performance of different battery models in a MATLAB/Simulink simulation of an EV powertrain. The authors conclude that a dynamic equivalent circuit model provides the most accurate and reliable results for battery behavior in EV powertrain simulations.

3. **Optimal Control of HEV Powertrain using Dynamic Programming and MATLAB/Simulink by Dong et al. (2020):**
   This paper proposes an optimal control strategy for HEV powertrain based on dynamic programming and simulated in MATLAB/Simulink. The authors show that the proposed strategy results in significant

improvements in fuel economy and vehicle performance compared to conventional control methods.

4. **A Review of Powertrain Modeling and Simulation for Hybrid Electric Vehicles by Asadi et al. (2020):**
   This review paper provides a comprehensive overview of powertrain modeling and simulation techniques for HEVs, including the use of MATLAB/Simulink. The authors discuss the different components of an HEV powertrain and their modeling considerations, as well as the importance of control strategies and optimization techniques.

5. **Modeling and Simulation of Electric and Hybrid Electric Vehicles using MATLAB/Simulink: A Comprehensive Review by Singh et al. (2022):** This review paper summarizes recent research on the modeling and simulation of EV and HEV powertrains using MATLAB/Simulink. The authors discuss the different modeling approaches for various powertrain components and their integration into a complete system. The paper also highlights the importance of simulation for design optimization and control strategy development.

6. **Design and Simulation of Electric Vehicle using BLDC Motor by Zhang et al. (2019):**
   This study presents the design and simulation of an EV using a BLDC motor and MATLAB/Simulink. The authors evaluate the performance of the motor under different driving conditions, such as acceleration, cruising, and braking. They also optimize the control strategy for the motor using a fuzzy logic controller. The study concludes that the BLDC motor is suitable for EVs due to its high efficiency, low cost, and simple structure. The authors suggest that further research is needed to improve the motor's thermal management and reduce its noise and vibration.

7. **Performance Analysis of Electric Vehicle using PMSM Motor with MATLAB/Simulink by Rana et al. (2021):**
   This paper presents the performance analysis of an EV using a PMSM motor and MATLAB/Simulink. The authors investigate the effects of motor parameters, such as the number of poles, on the motor's torque and efficiency. They also optimize the control strategy for the motor using a proportional-integral (PI) controller. The study concludes that the PMSM motor is suitable for EVs due to its high power density, high torque, and low rotor inertia. The authors suggest that further research is needed to improve the motor's thermal management and reduce its cogging torque.

8. **Design and Simulation of Electric Vehicle using DC Motor with MATLAB/Simulink by Bhattacharjee et al. (2020):**
   This study presents the design and simulation of an EV using a DC motor and MATLAB/Simulink. The authors investigate the effects of motor parameters, such as the armature resistance and inductance, on the motor's performance. They also optimize the control strategy for the motor using a PI controller. The study concludes that the DC motor is suitable for EVs due to its simplicity, low cost, and wide availability. The authors suggest that further research is needed to improve the motor's efficiency and reduce its mechanical losses.

9. **Comparative Analysis of BLDC and PMSM Motors for Electric Vehicle Applications by Patel et al. (2021):**
   This paper presents a comparative analysis of BLDC and PMSM motors for EV applications using MATLAB/Simulink. The authors investigate the effects of motor parameters, such as the number of poles and the rotor flux, on the motor's torque and efficiency. They also compare the control strategies for the two motors, such as the PI controller and the sliding mode controller. The study concludes that both BLDC and PMSM motors are suitable for EVs, depending on the specific application and performance requirements. The authors suggest that

further research is needed to improve the motors' thermal management and reduce their magnetic losses.

Conclusion: MATLAB/Simulink has become a popular tool for simulating and optimizing EV and HEV powertrain systems. Recent research has demonstrated the importance of accurate modeling and simulation in the design and optimization of powertrain components and control strategies. The reviewed papers have provided valuable insights into the challenges and opportunities in EV and HEV powertrain design and optimization, as well as the different modeling and simulation techniques that can be used to address these challenges.

# Chapter 3 Electric and Hybrid Electric Vehicle Powertrain Component and Architectures

## 3.1 Introduction

When selecting a powertrain for an electric or hybrid electric vehicle (HEV), there are several factors to consider in order to achieve good performance. Here are some important considerations:

- **Battery capacity and type:** The battery is the heart of an electric or HEV powertrain, and its capacity and type can greatly affect the vehicle's performance. A larger battery capacity typically means greater range and more power, while the type of battery (e.g., lithium-ion, nickel-metal hydride) can affect the vehicle's weight, cost, and charging time.
- **Electric motor power and torque:** The electric motor is responsible for providing power to the wheels and can greatly impact the vehicle's acceleration and top speed. Higher power and torque ratings generally result in better performance, but also increase the cost and weight of the powertrain.
- **Transmission type:** The type of transmission can also impact performance. Electric vehicles typically have a single-speed transmission, while HEVs may use a conventional transmission with multiple gears. The transmission can affect acceleration, top speed, and efficiency.
- **Regenerative braking:** Regenerative braking is a feature that stores kinetic energy from the motion of the vehicle in the battery. This can improve the vehicle's efficiency and extend its range.
- **Overall weight and aerodynamics:** The weight and aerodynamics of the vehicle can greatly affect its performance, especially in terms of acceleration and efficiency. A lighter vehicle with better aerodynamics will generally perform better.

- **Hybrid vs. fully electric:** If the driving requirements include long distances or frequent highway driving, a hybrid electric vehicle may be a better choice as it has a gasoline engine to provide extra power and extend the range. However, for short-distance commuting or city driving, a fully electric vehicle may be a better choice as it can provide better performance and efficiency.
- **Efficiency:** The powertrain should be designed for maximum efficiency to provide good performance and range. This includes optimizing the motor and battery performance, reducing weight, and minimizing energy losses through the drivetrain.

Ultimately, the best powertrain for a given electric or HEV vehicle will depend on the specific requirements and preferences of the driver. By considering the factors listed above, however, it is possible to select a powertrain that will provide good performance while also balancing cost, efficiency, and range.

## 3.2 Selection of EV and HEV Battery

The selection of a battery for an electric or hybrid electric vehicle depends on various factors, including the required range, performance, weight, and cost. Here are some general tips that can help in selecting a battery for an electric or hybrid electric vehicle:

- Energy density: The amount of energy a battery can store per unit of weight or volume depends on its energy density. A higher energy density battery will provide a longer range and better performance but may be more expensive.
- Battery chemistry: There are various battery chemistries, including lithium-ion, nickel-metal hydride, and lead-acid, have different characteristics, including energy density, power output, cycle life, and safety. Lithium-ion batteries are the most commonly used in electric and hybrid electric vehicles due to their high energy density, long cycle life, and low self-discharge rate.

- Battery pack configuration: The battery pack can be configured in different ways, such as series or parallel, to meet the voltage and current requirements of the electric or hybrid electric vehicle. A series configuration increases the voltage, while a parallel configuration increases the current.
- Battery management system(BMS): BMS monitors the state of charge, temperature, and voltage of the battery cells to ensure safe and efficient operation. It also helps to extend the battery life and prevent overcharging or overheating.
- Cost: The cost of the battery is an important factor in the selection process. While higher energy density batteries may provide better performance, they are also more expensive. It's important to consider the cost per kWh of the battery and the overall cost of the electric or hybrid electric vehicle.

## 3.3 Selection of Traction Motor for HEV and EV

The selection of a traction motor for an electric or hybrid electric vehicle (EV or HEV) depends on several factors such as vehicle weight, power requirements, desired acceleration performance, operating conditions, and cost. Here are some key considerations when selecting a traction motor for an EV or HEV:

- Power and torque requirements: The traction motor must be capable of providing the required power and torque to propel the vehicle. This depends on factors such as vehicle weight, desired acceleration performance, and operating conditions. The power and torque requirements are typically calculated based on the vehicle's performance specifications.
- Motor type: There are several types of electric motors used in EVs and HEVs, incorporating switching reluctance motors (SRMs), permanent magnet synchronous motors (PMSMs), and AC induction motors. Each type has its own advantages and disadvantages, and the selection of the motor type depends on the specific application.

- Efficiency: The efficiency of the motor is an important consideration since it directly affects the range of the vehicle. Higher efficiency motors will allow the vehicle to travel farther on a single charge.
- Thermal Management: The traction motor generates heat during operation, and effective cooling is required to ensure the motor operates at its optimum temperature. The cooling system can be air or liquid cooled, depending upon specific application.
- Cost: The cost of the motor is an important consideration, as it directly affects the overall cost of the vehicle. However, it is important to balance cost with performance and efficiency to ensure the best overall value.
- Reliability and Durability: The motor should be reliable and durable to ensure long-term performance and minimal maintenance requirements.
- Noise and Vibration: The motor should be designed to minimize noise and vibration to provide a comfortable driving experience.

Integration with the power electronics: The traction motor must be integrated with the power electronics system, which includes the motor controller and battery management system. The motor and power electronics must be designed to work together for optimal performance.

## 3.4 Selection of Transmission for EV and HEV

The selection of the type of transmission for hybrid electric vehicles (HEVs) and electric vehicles (EVs) depends on several factors, including performance, efficiency, and cost.

- Single-Speed Transmission: One of the most common types of transmissions used in EVs is a single-speed transmission. It is simple, lightweight, and has fewer moving parts, which makes it more reliable and efficient. The single-speed transmission is best suited for low-speed, high-torque applications such as city driving.
- Multi-Speed Transmission: Multi-speed transmissions are more complex and heavier than single-speed transmissions but can provide better performance and efficiency at higher speeds. They are suitable for

EVs and HEVs that require higher top speeds and acceleration. However, they can be more expensive to produce and maintain.

- Continuously Variable Transmission (CVT): A CVT is a form of gearbox that can switch between any number of gear ratios without losing efficiency. CVTs are highly efficient and can provide smoother acceleration and better fuel economy. They are well suited for HEVs, where the electric motor and the internal combustion engine need to work together efficiently.

In summary, the selection of the type of transmission for EVs and HEVs depends on the vehicle's intended use, power requirements, and cost constraints. A single-speed transmission is suitable for city driving, while a multi-speed transmission or a CVT is best suited for higher speeds and acceleration.

## 3.5 Regenerative Braking in HEV and EV

Regenerative braking is a technology used in electric and hybrid electric vehicles to recuperate energy that would be wasted during braking otherwise.. When a driver applies the brakes, the electric motor in the vehicle are used as generators, converting the kinetic energy of the vehicle into electrical energy. The vehicle's battery stores this energy for later use.

In a pure EV, regenerative braking is the primary means of slowing down the vehicle, as there is no engine braking to rely on. In a hybrid vehicle, regenerative braking is used in combination with the traditional friction to reduce speed and conserve energy.
The amount of energy that can be recovered through regenerative braking depends on several factors, including the speed of the vehicle, the weight of the vehicle, and the state of charge of the battery. In general, regenerative braking is most effective at lower speeds and when the battery is not fully charged.

One of the benefits of regenerative braking is that it can help to extend the range of an electric vehicle, as it allows for the recovery of energy that would otherwise be lost during braking. It can also help to reduce wear and tear on the vehicle's friction brakes, as they are used less frequently.

## 3.6 Power Electronics in EV and HEV

Power electronics components are essential parts of hybrid electric vehicles (HEVs) and electric vehicles (EVs). They are employed to control the power flow between the battery, electric motor, and other components, to enhance the efficiency of the vehicle and extend the range.

Here are some of the key power electronics components used in EVs and HEVs:

- Inverter: This device converts DC power from the battery to AC power to drive the electric motor. The inverter controls the speed and torque of the motor by adjusting the frequency and amplitude of the AC power.
- DC-DC Converter: The battery's high voltage DC electricity is converted by this device into the low voltage DC power required to operate the vehicle's accessories and subsystems.
- On-board charger: This device transforms AC power from a charging station to DC electricity so that the battery can be charged.
- Battery Management System (BMS): This system monitors and controls the charging and discharging of the battery, as well as ensuring that each cell in the battery is operating within safe limits.
- Power Distribution Unit (PDU): This device distributes the power from the battery and the DC-DC converter to the different subsystems and accessories in the vehicle.

Overall, power electronics components play a critical role in the operation HEVs and EVs, helping to optimize efficiency and performance while minimizing energy loss.

## 3.7 Vehicle Weight and Performance

The curb mass (mv) of a vehicle is its overall weight with all of its standard parts, lubricants, and a full tank of fuel, but without any passengers or luggage. When curb mass added with the passengers mass and luggage make up the gross vehicle mass (MGV) of a vehicle.

In terms of the curb mass of the vehicle, the components' positions in respect to the suspension system enable us to distinguish between sprung mass and unsprung mass. The term "spring mass" refers to the portion of the curb mass of the vehicle that is supported by suspension, including moving suspension components. Unsprung mass is the portion of the vehicle's curb mass that is still being carried by its wheels and moving along with it.
The front-to-rear mass distribution is essential for a vehicle's balance and smooth ride. Axle-to-axle distances can be used to define the mass distribution. Let

l = axle-to-axle length
a = vehicle center of gravity to front axle, known as front longitudinal length
b = vehicle center of gravity to rear axle, known as rear longitudinal length

The front vehicle mass is $mvf = (b/l)*mv$ And the rear vehicle mass is a $mvr = (a/l)*mv$

## 3.8 EV Architecture and Design

The BEV with only one or more electric machines as its power source has the most basic architecture and doesn't require power blending. In Figure 3.1, the intricate structure of an EV system and the interactions between its numerous components are depicted. The motor, controller, power source, and transmission are an EV system's four main parts.

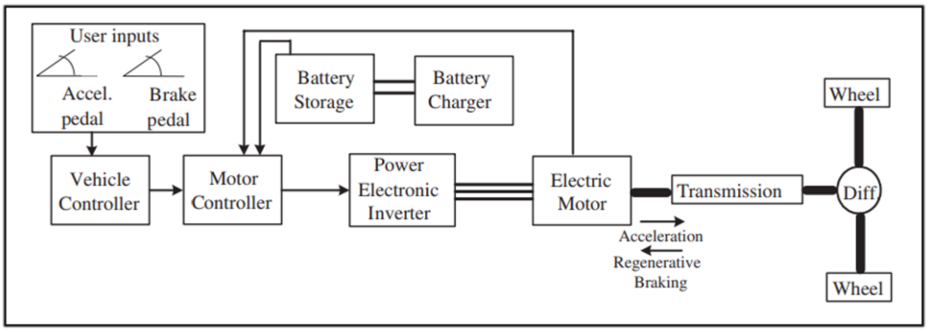


Fig. 3.1: The main electrical parts of an EV system

.

## 3.9 HEV Architecture and Design

### 3.9.1 Series and Parallel Hybrid

Two fundamental configurations, parallel and series, are where the HEVs originated. If only one energy converter can supply propulsion power, the hybrid is referred to as a series hybrid. In this setup, the IC engine serves as the prime mover to power an electric generator, which in turn provides power to the propulsion motor, battery, or other energy storage system. Figure 3.2 displays the component positioning of a series HEV.

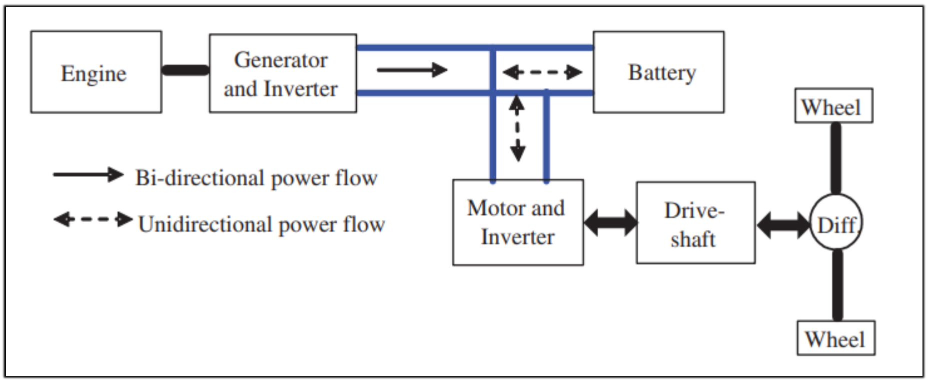


Fig. 3.2: Series HEV powertrain

A parallel hybrid is one in which the wheels can receive propulsion power from multiple energy conversion devices. A mechanical coupling is used to combine the torque produced by the parallel configuration of the electric motor and IC engine. Figure 3.3 depicts the component placement of a parallel hybrid.

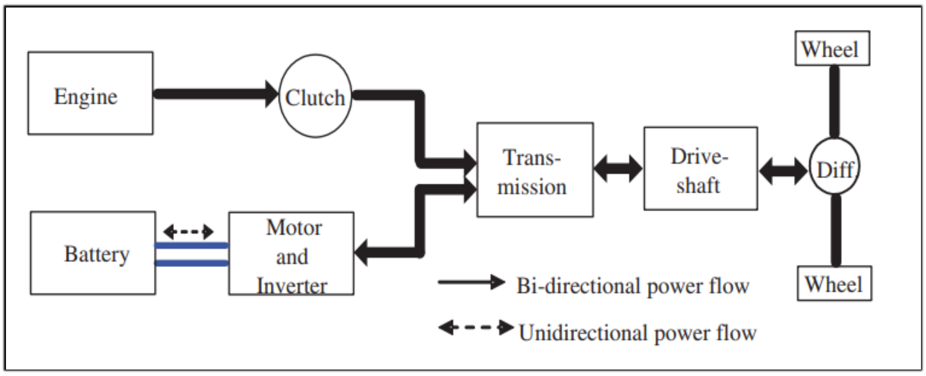


Fig. 3.3: Parallel HEV powertrain

Here are some advantages of a series hybrid architecture:

- Better fuel efficiency: Because the combustion engine is not directly connected to the wheels, it can operate at a constant speed and optimal load, which results in better fuel efficiency.
- Reduced emissions: Since the combustion engine is only used to generate electricity, it can be designed to run at its most efficient point, which results in reduced emissions compared to a traditional gasoline engine.
- Reduced noise: Because the wheels are driven by electric motors, there is no noise from the transmission or exhaust, resulting in a quieter ride.
- Regenerative braking: With a series hybrid architecture, the electric motors can be used to slow down the vehicle and generate electricity, which is stored in the battery. This regenerative braking helps to recharge the battery and reduces wear on the brakes.
- Flexibility: A series hybrid architecture can be designed to run on different fuels, such as gasoline, diesel, or biofuels, or even hydrogen fuel cells. This provides flexibility for manufacturers to meet different market demands and regulations.

Some advantages of a parallel hybrid architecture:

- Improved performance: With both the electric motor and the combustion engine working together, a parallel hybrid architecture can provide improved acceleration and overall performance compared to a traditional gasoline engine.

- Increased range: Because the combustion engine can also drive the wheels, a parallel hybrid architecture can provide increased range compared to a purely electric vehicle, making it more practical for longer journeys.
- Flexibility: A parallel hybrid architecture can be designed to run on different fuels, such as gasoline, diesel, or biofuels, or even hydrogen fuel cells. This provides flexibility for manufacturers to meet different market demands and regulations.
- Regenerative braking: Like in a series hybrid architecture, a parallel hybrid architecture can also use regenerative braking to recharge the battery and reduce wear on the brakes.
- Lower emissions: While not as low as a purely electric vehicle, a parallel hybrid architecture can still reduce emissions compared to a traditional gasoline engine by using the electric motor to assist the combustion engine and by shutting off the engine when it is not needed, such as when idling or coasting.

### 3.9.2 Series-Parallel Hybrid

The advanced hybrids create a series-parallel hybrid architecture with the ability to sustain a charge by combining the advantages of series and parallel architectures. The IC engine in these combo hybrids also serves as the battery charger. With more mechanical links and controls than a series hybrid and an additional generator than a parallel hybrid, the architecture is comparatively more complex. The car's architecture is mostly parallel HEV with a slight addition of a series element. In situations where there is a protracted wait time, like at traffic lights or in a traffic congestion, the small series element makes sure that the battery charge is maintained.

The IC engine and electric motors are efficiently used by the controller for the series-parallel architectures to deliver up to their utmost potential through flexible adaptation with driving conditions.

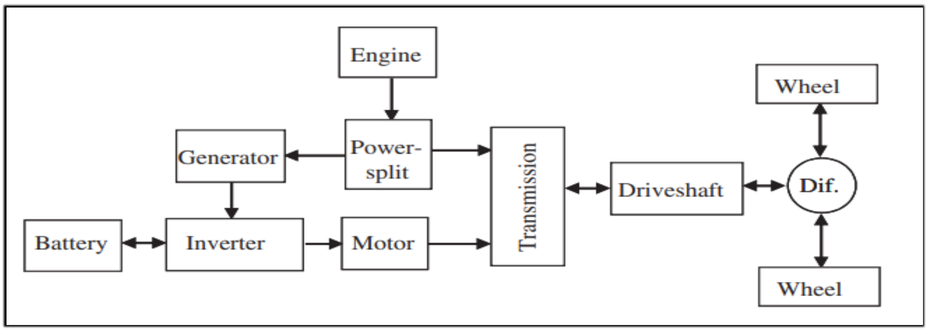


Fig. 3.4: Parallel and Series combination HEV

### 3.9.3 Series–Parallel 2 × 2 Hybrid

A series-parallel 2 x 2 vehicle architecture is shown in Figure 3.5 and consists of two electric motors, one IC engine, and a battery energy storage system. The architecture offers the same appealing features of series-parallel architecture as outlined in the previous section, but with built-in four-wheel drive capability. The engine is connected to one set of wheels, typically the front wheels, using a gearbox. The second set of wheels, typically the rear wheels, are mechanically attached to one electric machine, which is mechanically coupled to the engine. The electric generator or machine that is situated up front is usually used for starting and generation. Regenerative braking and traction are performed by the motor at the back.

The engine powers the generator in addition to being used for traction. The rear-mounted electric motor propels the rear wheels while the engine propels the front wheels during acceleration. However, the front electric machine can be used as a motor to add torque at the front axle at periods of peak acceleration demand. Electronic controls are used to blend the torque between the front and back axles; a mechanical powersplit mechanism, like the one used in the Prius series-parallel architecture, is not necessary. The complexity of the control algorithm and the mounting specifications for the engine components in both the front and rear axles are drawbacks of the series-parallel 2 2 architecture.

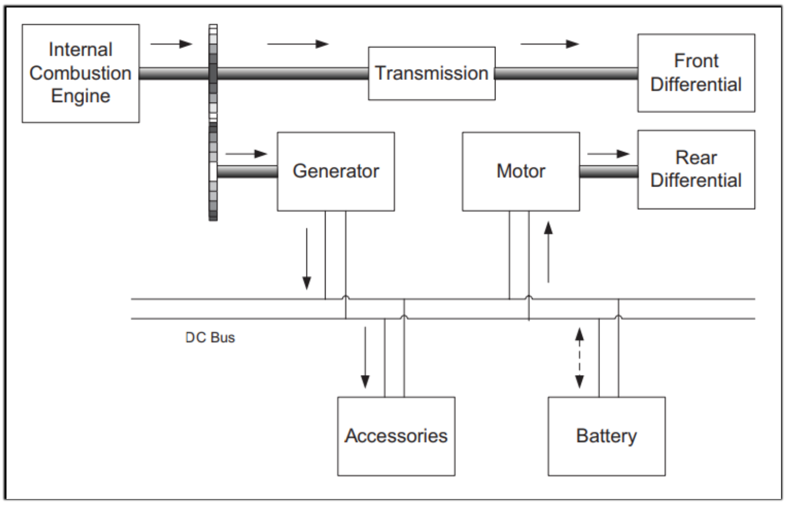


Fig. 3.5: Series–parallel 2 × 2 vehicle architecture

# Chapter 4 Component Modelling in Simulink and Simscape

Component modeling in Simulink and Simscape is an effective way to simulate and analyze the performance of electric vehicles. Simulink and Simscape are software tools developed by MathWorks that enable engineers to model, simulate, and analyze dynamic systems.

To model an electric vehicle in Simulink and Simscape, you would typically start by identifying the major components of the vehicle, such as the battery, motor, controller, and drive train. You would then create models of these components using the blocks and tools provided by Simulink and Simscape.

For example, you could model the battery as a simple circuit with a voltage source and resistance, or you could use a more detailed model that includes factors such as state of charge and internal resistance. Similarly, you could model the motor as a simple block that converts electrical energy to mechanical energy, or you could use a more detailed model that includes factors such as torque and speed.
Once you have created models of the individual components, you can integrate them into a larger model of the complete electric vehicle. This can be done by

connecting the blocks and tools in Simulink and Simscape using wires and other connectors. You can then simulate the behavior of the vehicle under different conditions, such as different driving speeds, road grades, and battery charge levels.

Simulink and Simscape provide a range of tools and features for analyzing the performance of the vehicle model, such as simulation results visualization, data analysis, and optimization. You can use these tools to identify areas for improvement in the vehicle design, such as optimizing the battery size or improving the efficiency of the motor.
Overall, Simulink and Simscape are powerful tools for modeling and analyzing the performance of electric vehicles, and can be used to improve the design and performance of these vehicles.

## 4.1 Physical Network Approach To Modelling Using Simscape

Simscape is a toolset that is part of the Simulink environment.It comes with a number of simulation tools and block libraries for modelling physical systems. The Physical Network technique, which differs from the conventional Simulink modelling approach and is particularly effective for modelling systems with real physical components, is the foundation upon which Simscape is based.

Similar to how real components like mass, spring, etc. are connected when Simscape bricks are connected together. Simscape diagrams effectively replicate the design of the actual system. Similar to real systems, when connecting Simscape blocks, flow directions are not need to be stated. The Through Variable (TV) and Across Variable (AV), which together make up power in this physical network architecture, are two different variables.

| **Physical Domain** | **Across Variable** | **Through Variable** |
|---|---|---|
| Electrical | Voltage | Current |
| Hydraulic | Pressure | Flow rate |
| Magnetic | Magnetomotive force (mmf ) | Flux |

| | | |
|---|---|---|
| Mechanical rotational | Angular velocity | Torque |
| Mechanical translational | Translational velocity | Force |

Table 4.1: In several areas, through and across variables

## 4.2 Introduction To Vehicle Dynamics And Simscape

A huge library of elements can be searched for and found in the Simscape library once Simscape has been started (Figure 2.5). There are a few subfolders in the Simscape library.

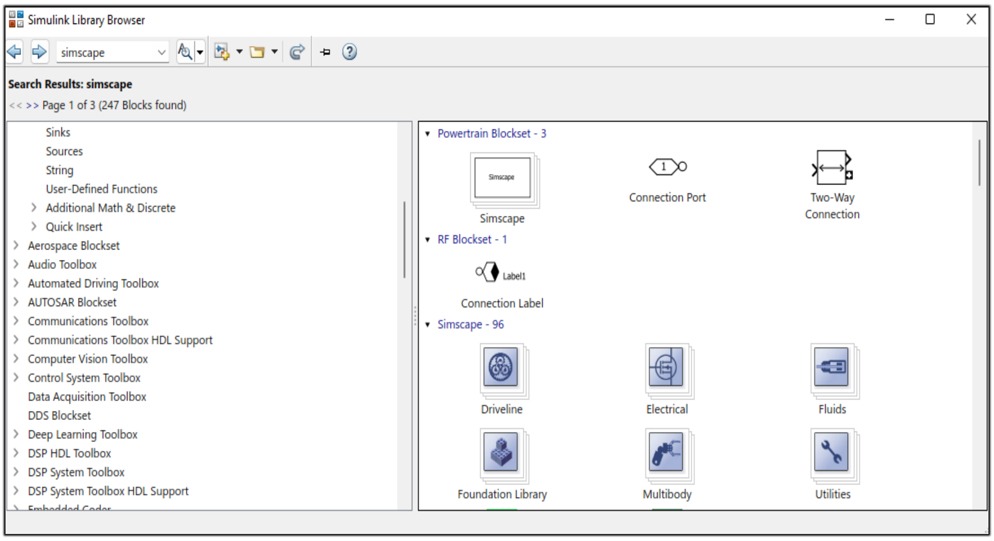


Fig. 4.1: Simscape library

The Foundation Library, the Driveline Library, and the Electrical Library are the three that we will use most frequently for this assignment.

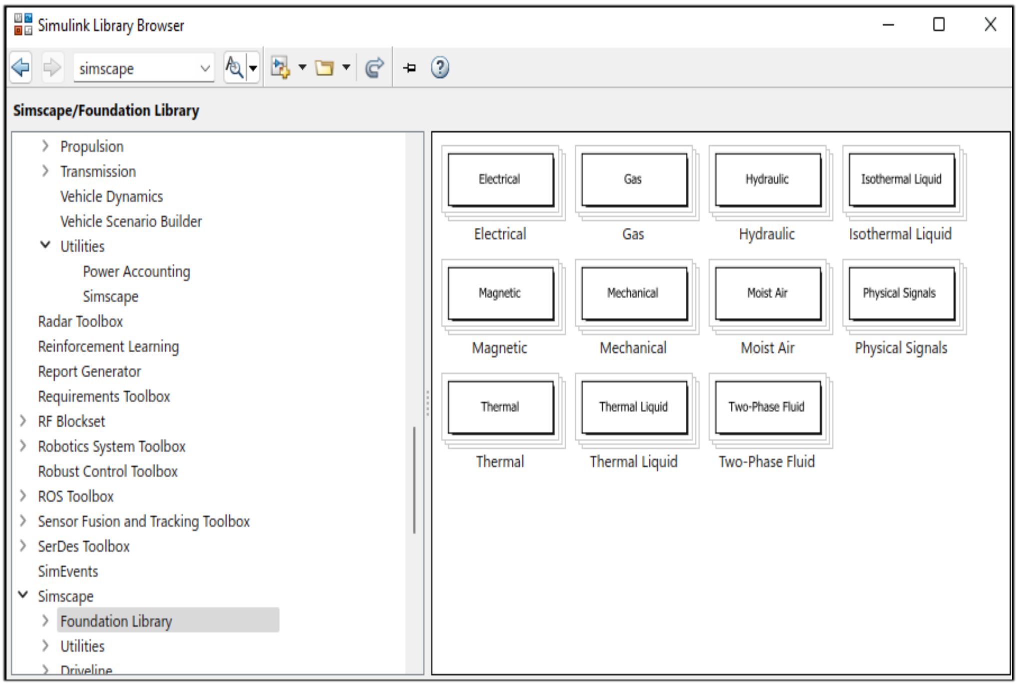


Fig. 4.2: Libraries that are part of the foundation library Simscape

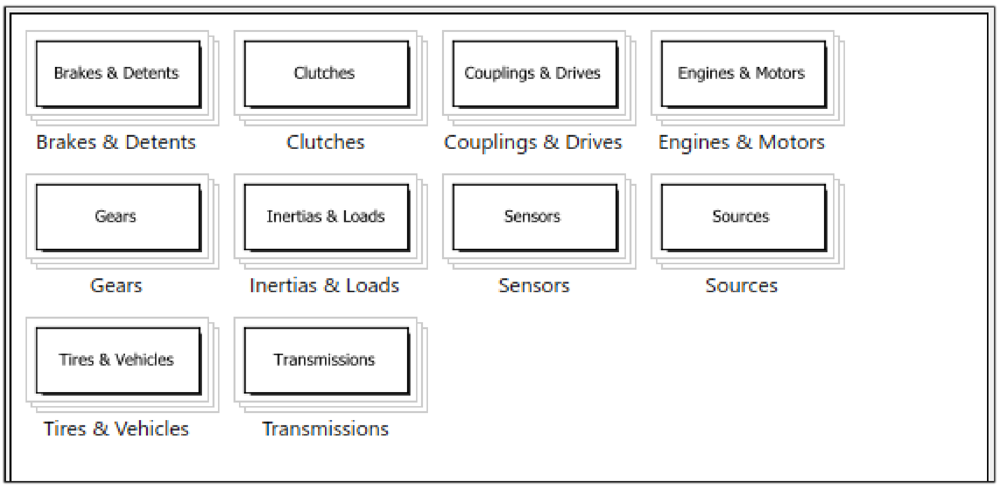


Fig. 4.3: Driveline library options offered by Simscape

## 4.3 Modelling of Energy Source

Building a battery pack for an electric vehicle involves connecting multiple individual cells together to create a larger power source. Here are the basic steps to do so:

- Determine the required voltage and capacity: The first step is to determine the required voltage and capacity for your electric vehicle. This will depend on the motor and other components of the vehicle, as well as the desired range.

- Select the battery cells: Choose battery cells that meet the voltage and capacity requirements, and that are suitable for high-power applications. Lithium-ion cells are commonly used in electric vehicles.
- Connect the cells in series: Connect the cells in series by attaching the positive terminal of one cell to the negative terminal of the next cell. This will increase the voltage of the pack. For example, if you have ten 3.7V cells, connecting them in series will create a 37V pack.
- Connect the cells in parallel: Connect cells in parallel by attaching the positive terminals of all cells to each other, and the negative terminals of all cells to each other. This will increase the capacity of the pack. For example, if you have ten 3.7V cells with a capacity of 2Ah each, connecting them in parallel will create a pack with a capacity of 20Ah.
- Balance the cells: When connecting cells in series, it is important to ensure that the voltage of each cell is balanced. This can be done using a battery management system (BMS), which monitors and balances the voltage of each cell.
- Enclose the pack: Enclose the pack in a suitable container and connect it to the electric vehicle's electrical system.

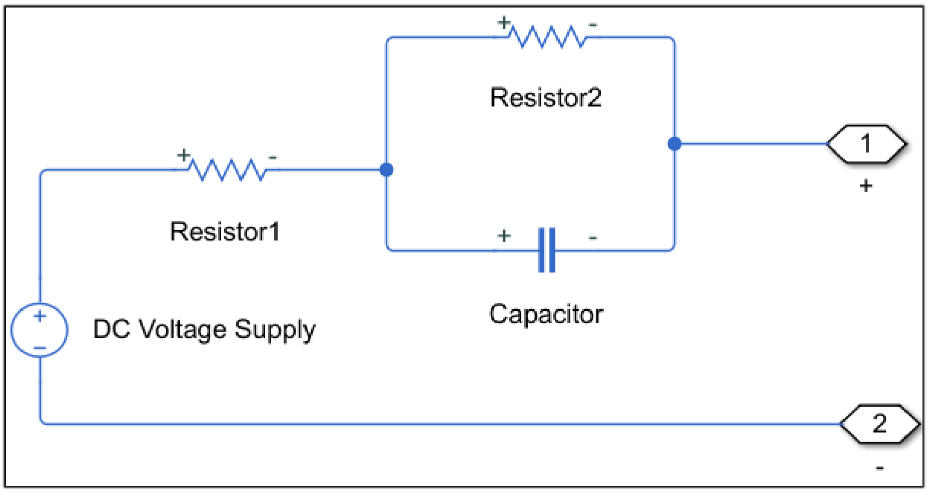


Fig 4.4: Basic design of cell

Connection a four cell in series to make 48 V battery pack if each cell have voltage 12 V.

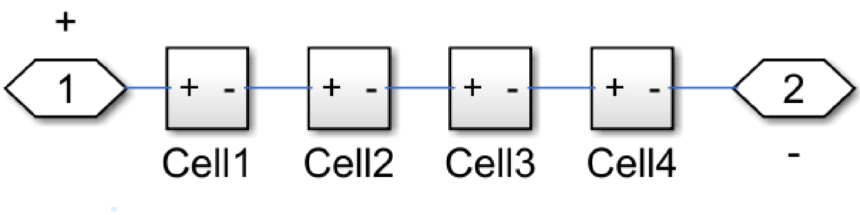


Fig 4.5: 48V Battery Pack

Or we can implement a generic battery model for most popular battery types. Temperature and aging (due to cycling) effects can be specified for Lithium-Ion battery type.

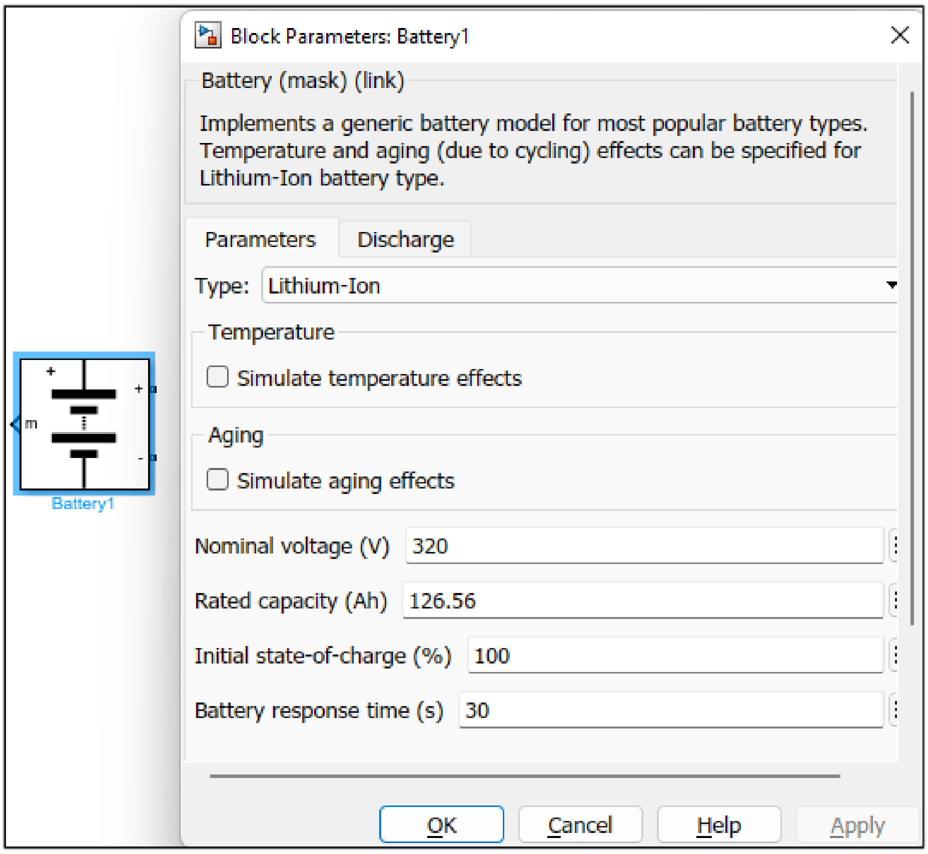


Fig 4.6: Parameter to Control Li-ion Battery

Temperature and aging can have significant effects on the performance and lifespan of electric vehicle lithium-ion batteries. Here are some key points to consider:

- Temperature: Lithium-ion batteries perform best at moderate temperatures (typically between 20°C and 25°C). When the temperature rises above this range, the battery's performance and lifespan can be negatively impacted. High temperatures can accelerate the degradation of the battery, leading to reduced capacity and a shorter lifespan. Similarly, low temperatures can cause the battery's capacity to drop temporarily, and can also cause damage to the battery if it gets too cold.

- Aging: All batteries experience some degree of degradation over time, and lithium-ion batteries are no exception. The amount of degradation will depend on a number of factors, including how the battery is used and maintained, as well as the quality of the battery itself. Over time, the battery's capacity will gradually decrease, and it will take longer to charge and discharge.
- Combined effects: The combination of temperature and aging can have a compounding effect on the battery's performance and lifespan. For example, if a battery is subjected to high temperatures for extended periods of time, it will degrade faster than a battery that is kept at a moderate temperature. Similarly, if a battery is heavily used and is constantly being charged and discharged, it will degrade faster than a battery that is only used occasionally.

## 4.4 Modelling of Power Convertor Device

**4.4.1 PID Controller:** In order to control the motor torque or speed in electric vehicles (EVs), a PID (Proportional-Integral-Derivative) controller is frequently employed. To modify the torque or speed of an electric motor, the PID controller receives feedback from sensors like the motor encoder or current sensor.

The Proportional (P) term of the PID controller is responsible for generating a control signal that is proportional to the error between the desired and actual motor torque or speed. The Integral (I) term of the PID controller accumulates the error over time and generates a control signal that helps to reduce steady-state error. The Derivative (D) term of the PID controller uses the rate of change of the error to generate a control signal that helps to reduce overshoot and oscillations.

In an EV, the PID controller is used to regulate the motor torque or speed based on the driver's input and the vehicle's operating conditions, such as the battery state-of-charge and temperature. The PID controller adjusts the motor torque or speed to maintain the desired vehicle speed and acceleration while minimizing energy consumption

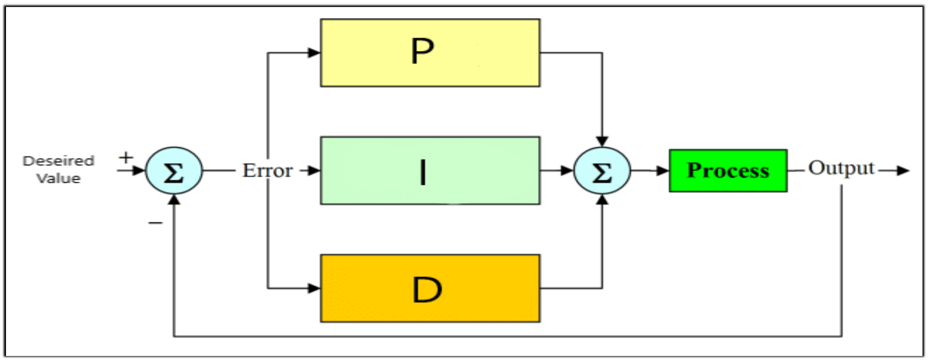


Fig 4.7: MATLAB Block PID Controller

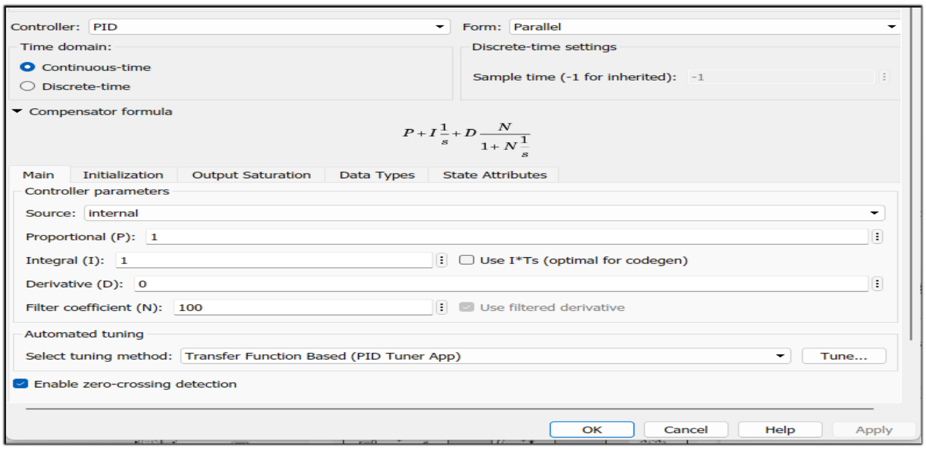


Fig 4.8: Parameter to tune PID controller

### 4.4.2 Invertor:

An inverter is a critical component of an electric vehicle (EV) powertrain system, responsible for converting the DC voltage from the battery into the AC voltage that is required to power the electric motor.

The inverter uses power electronics, such as insulated gate bipolar transistors

(IGBTs), to switch the DC voltage from the battery into a high-frequency AC voltage that is then transformed into a lower voltage suitable for the motor. The inverter is also responsible for controlling the frequency, amplitude, and phase of the AC voltage, which determines the speed and torque of the motor.
In addition to its primary function of controlling the motor, the inverter also plays a critical role in managing the overall power flow within the vehicle. For example, the inverter may be used to control regenerative braking, where the motor acts as a generator to charge the battery during deceleration.

The inverter also typically includes various safety features, such as overcurrent and overvoltage protection, to ensure the safe and reliable operation of the EV powertrain system.

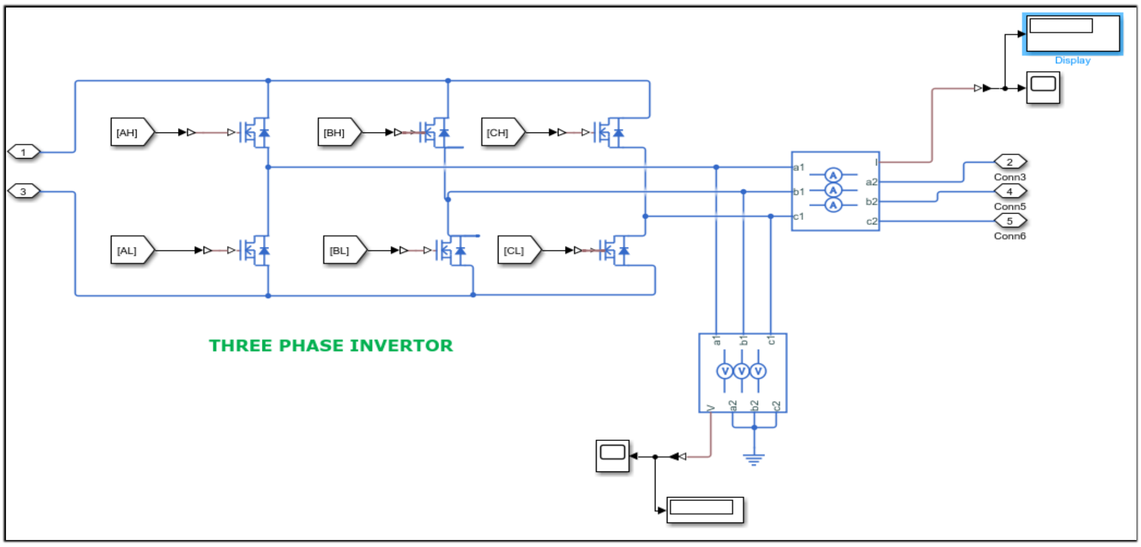


Fig 4.9: Implementation of 3-phase Invertor Using 6 IGBT switch

### 4.4.3 **DC-DC Convertor:** A DC-DC converter is an important component in an electric vehicle (EV) because it is responsible for converting the high-voltage DC power from the battery to the low-voltage DC power required by the vehicle's electrical system, such as the lighting, dashboard, and entertainment system.

The DC-DC converter is typically located between the high-voltage battery and the low-voltage electrical system of the vehicle. It steps down the voltage to the appropriate level, which can range from 12 volts to 48 volts depending on the vehicle.The converter also helps to maintain the voltage level of the low-voltage electrical system, even as the high-voltage battery charges and discharges. This is important to ensure that all the vehicle's electrical components operate reliably and efficiently.

In addition, the DC-DC converter can also serve as a source of power for auxiliary systems in the vehicle, such as the heating and air conditioning system, which can help to reduce the load on the high-voltage battery.

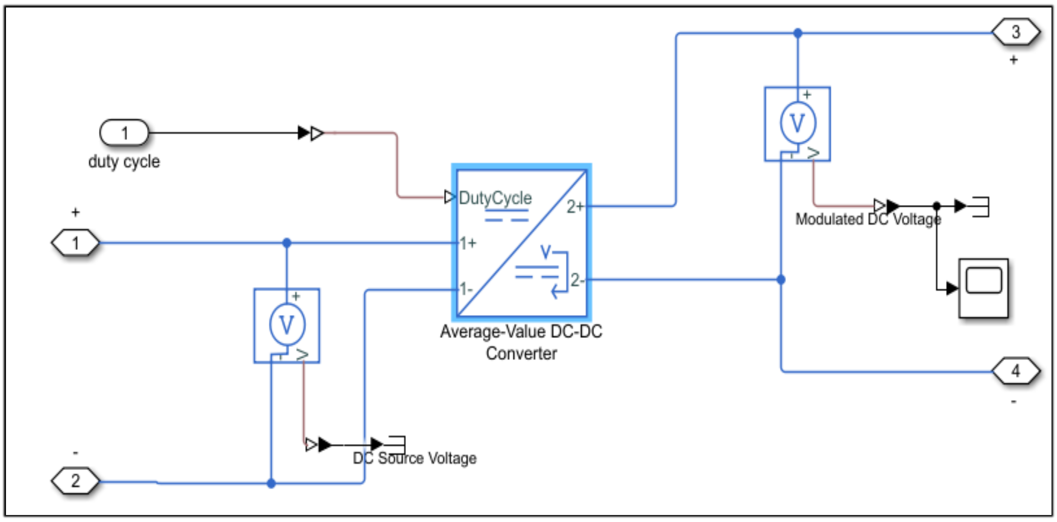


Fig 4.10: DC-DC Convertor MATLAB Block

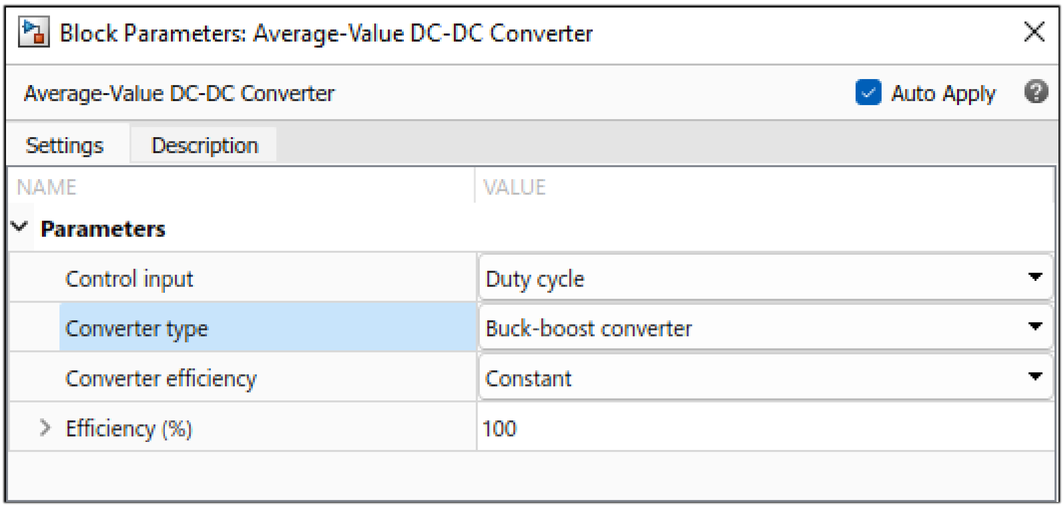


Fig 4.11: Parameter selection for DC-DC convertor

### 4.5 Vehicle Body

A two-axle vehicle body in longitudinal motion is represented by the Vehicle Body block. The number of wheels on each axle of the car may be the same or different. two wheels on the front axle and one wheel on the back, for instance. The size of the vehicle's wheels is presumptively the same. The vehicle's centre of gravity (CG) may also be on, near, or below the plane of movement.

The block takes into account weight distribution between axles caused by acceleration and road profile, as well as body mass, aerodynamic drag, road inclination, and other factors. Pitch and suspension dynamics are optional. When compared to the ground, the vehicle does not move vertically. The car's axles form a parallelogram that is level. This plane and the longitudinal direction, or x, are perpendicular to the axles. The normal, z, direction is always perpendicular to the axle-longitudinal plane when the vehicle is moving over an inclined slope,.

The variables in the vehicle motion model are defined in this figure and table.

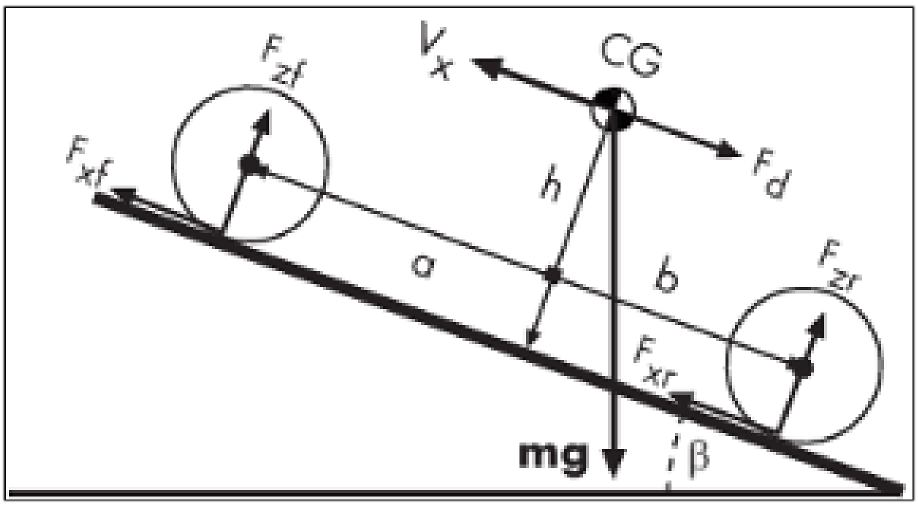


**Fig 4.12: Vehicle Dynamics and Motion**

## 4.6 Equations

The net outcome of all the forces and torques operating on the vehicle is the motion. The vehicle is propelled either forward or backward by longitudinal tyre forces. The vehicle's centre of gravity (CG) is where the weight mg of the vehicle is felt. The weight pulls the vehicle to the ground and pushes it in one of two directions, depending on the slope of the incline. The vehicle slows down due to aerodynamic drag whether it is moving forward or backward. To keep things simple, it is believed that the drag operates via the CG.

| **Symbol** | **Description** |
|---|---|
| $g$ | Gravitational acceleration |
| $\beta$ | Incline angle |
| $m$ | Mass of the vehicle |
| $h$ | Vehicle's centre of gravity's (CG) height above the ground |
| $a$, $b$ | Distances between the front and rear axles with relation to the common axle plane at the usual vehicle centre of gravity |
| $V_x$ | Velocity of the vehicle. When $V_x < 0$, the vehicle moves backward, When $V_x > 0$, the vehicle moves forward. |
| $V_w$ | Wind speed. When $V_w < 0$, the wind is tailwind, When $V_w > 0$, the wind is headwind. |
| $n$ | Number of wheels on each axle |
| $F_{xf}$, $F_{xr}$ | Longitudinal forces at the front and back ground contact locations, respectively, on each wheel |
| $F_{zf}$, $F_{zr}$ | At the rear and front ground contact sites, normal load forces are applied to each wheel. |
| $A$ | Effective frontal cross-sectional area of vehicle |
| $C_d$ | Aerodynamic drag coefficient |
| $\rho$ | Mass density of air |
| $F_d$ | Aerodynamic drag force |

Table 4.2: Constant used in vehicle dynamic equation

$$m\dot{V}_x = F_x - F_d - mg \cdot \sin\beta$$

$$F_x = n(F_{xf} + F_{xr})$$

$$F_d = \frac{1}{2} C_d \rho A (V_x + V_w)^2$$

The normal force acting on each front and rear wheel is determined by zero normal acceleration and zero normal pitch torque.

$$F_{zf} = \frac{-h(F_d + mg\sin\beta + m\dot{V}_x) + b \cdot mg\cos\beta}{n(a+b)}$$

$$F_{zr} = \frac{+h(F_d + mg\sin\beta + m\dot{V}_x) + a \cdot mg\cos\beta}{n(a+b)}$$

## 4.7 Model

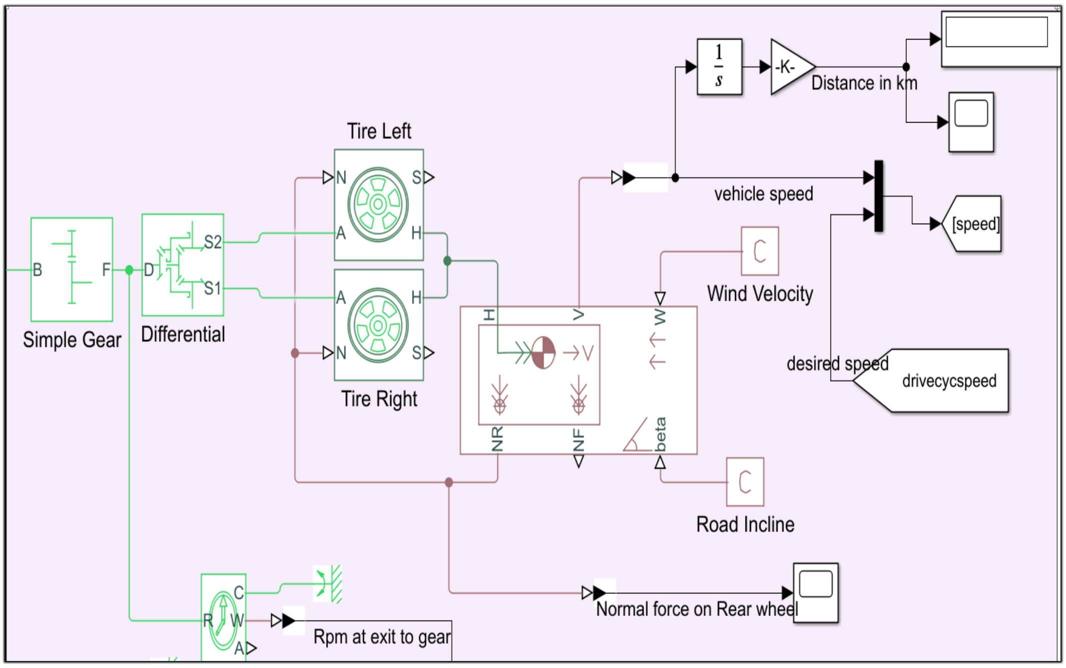


Fig 4.13: MATLAB Model of complete vehicle body

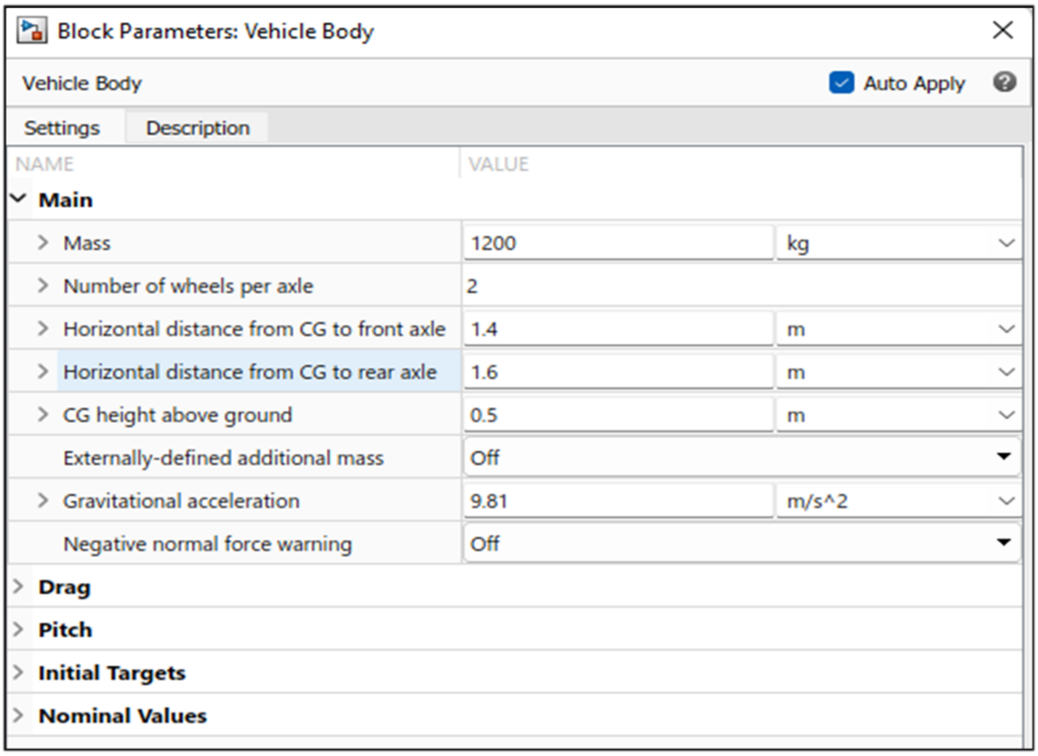


Fig 4.14: Represent Parameter of Vehicle Body

## 4.8 Vehicle Simulation In MATLAB for Different Architecture

### 4.8.1 Series Hybrid Powertrain

In this we implement series hybrid powertrain in MATLAB by using simscape, simulink, powertrain blockset libraries.

We test our result on Modified Indian Drive Cycle(MIDC).

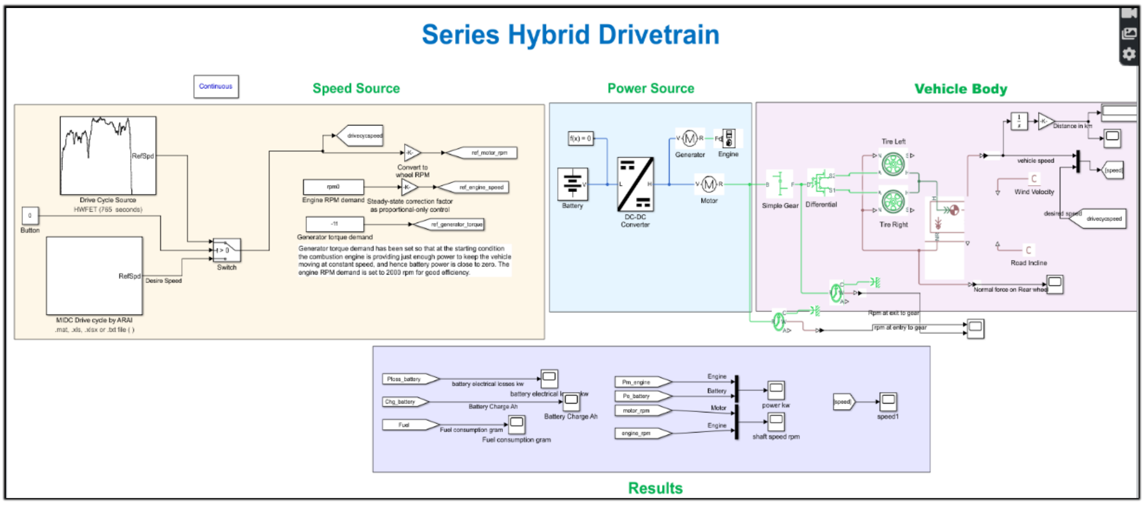


Fig 4.15: Model of Series Hybrid Powertrain in MATLAB

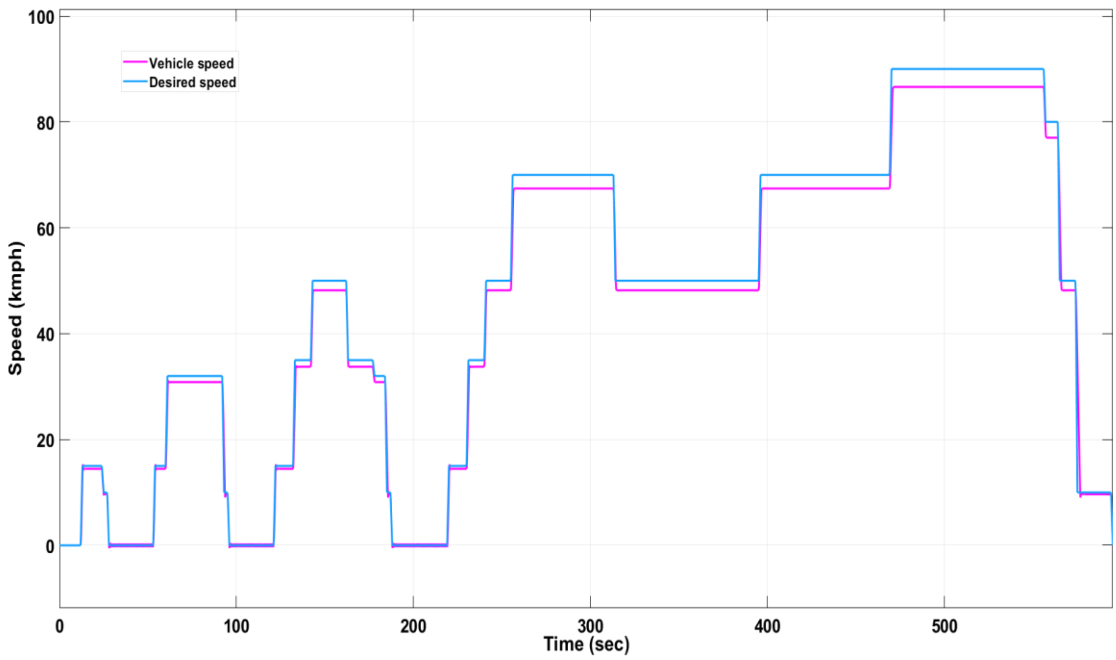


Fig 4.16: Vehicle following MIDC Speed profile

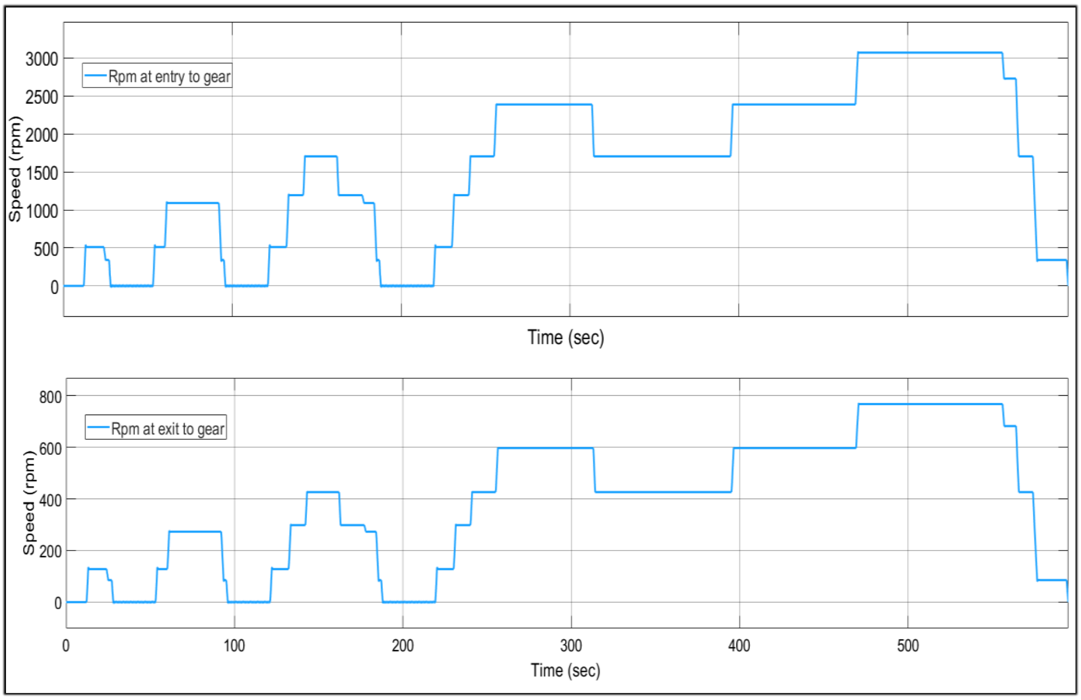


Fig 4.17: Change of speed using fixed gear having GR=4

When employing a single fixed gear with a gear ratio of 4, the rotational speed is reduced by 4 times, and the torque is multiplied by 4.

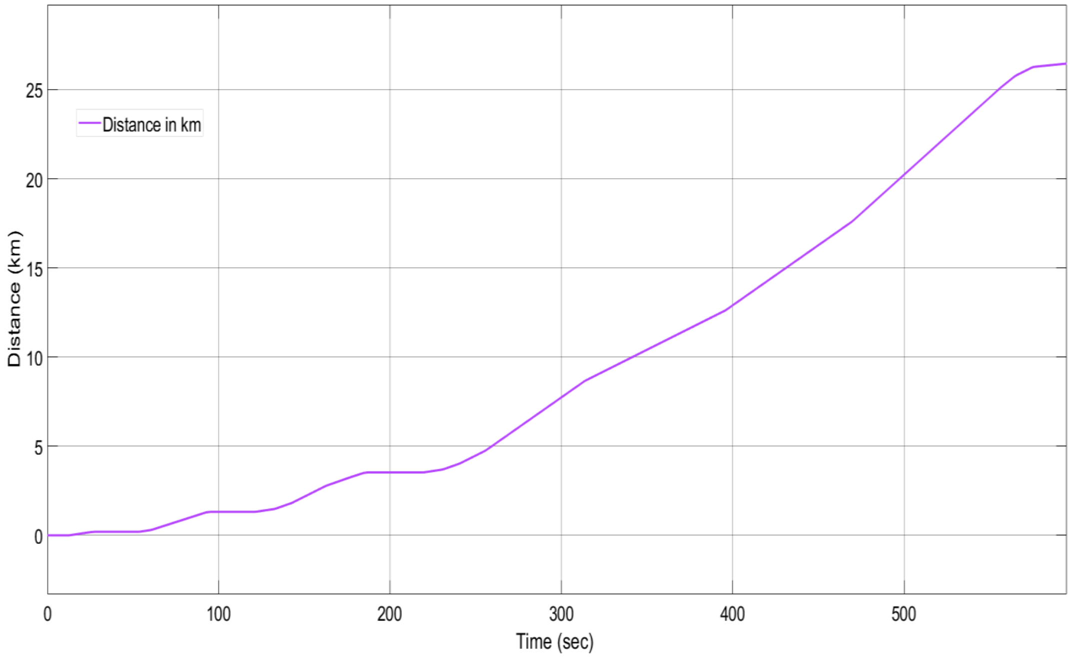


Fig 4.18: Distance travelled by series hybrid vehicle over one MIDC cycle

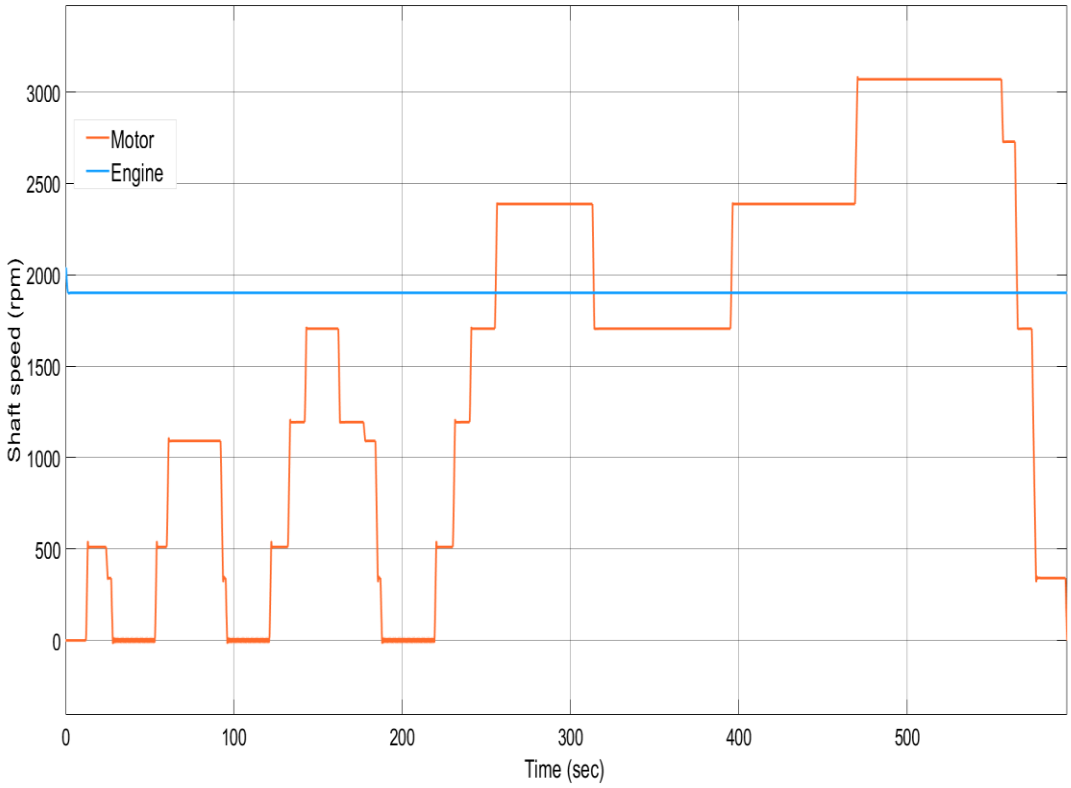


Fig 4.19: Engine and Motor shaft speed in series hybrid vehicle over one MIDC cycle

Figure 4.19 shows that the engine is operating at a steady speed in the region of optimal efficiency while the electric motor is meeting the load demand.

The battery charge level will be at 100% or very near to it at the start of a trip. The battery charge level will drop as you drive the car. The terrain, driving conditions, and vehicle speed are just a few of the variables that will affect how quickly the battery charge level depletes. The regenerative braking system utilises part of the energy that would otherwise be lost during braking to recharge the battery while the car is moving. On the graph, this appears as increases in the battery charge level.

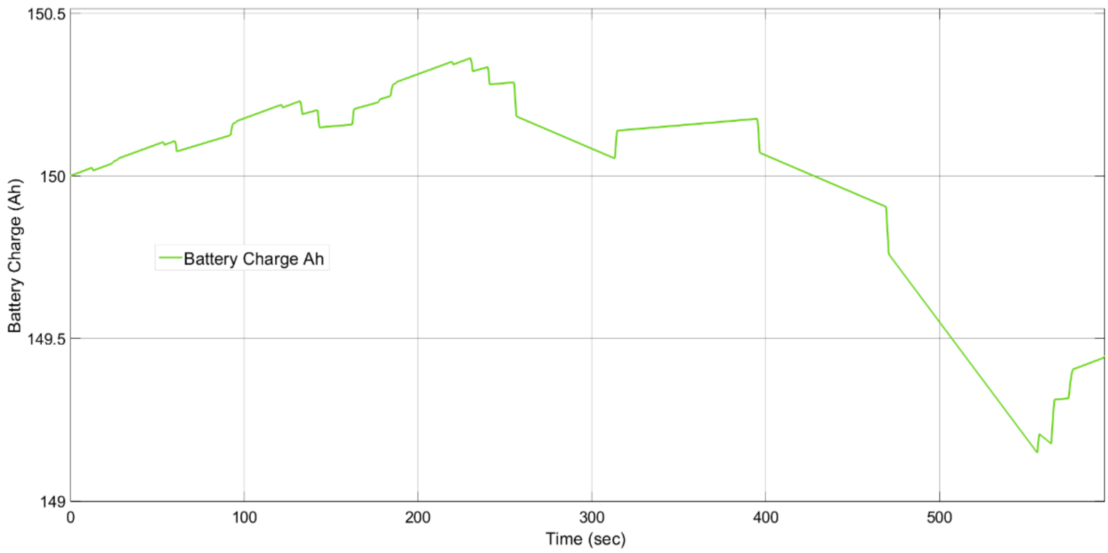


Fig 4.20. Battery Charge (Amphere-hour) over one MIDC cycle

Resistance, also known as Joule heating, can produce heat when a strong current passes through the battery and its connections. This heat loss is an energy loss from the battery that cannot be utilised to propel the car forward. The amount of heat loss increases with increasing current draw. We can see electrical losses due to high current in fig. 4.21

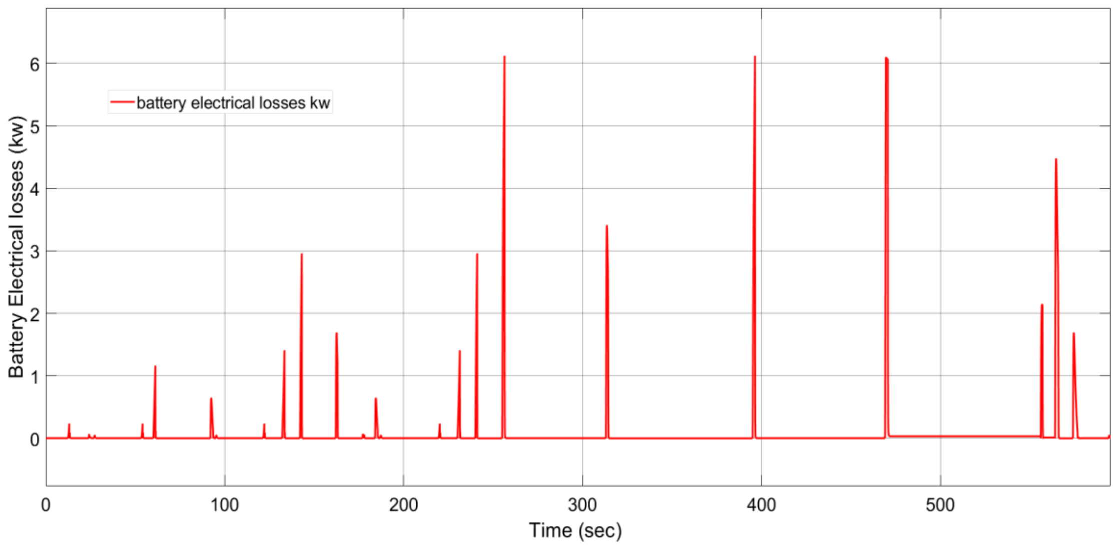


Fig 4.21. Battery Electrical Losses in series hybrid vehicle over one MIDC cycle

The vehicle's overall fuel consumption will be influenced by the engine's efficiency as well as other elements like battery capacity and electric motor energy efficiency.

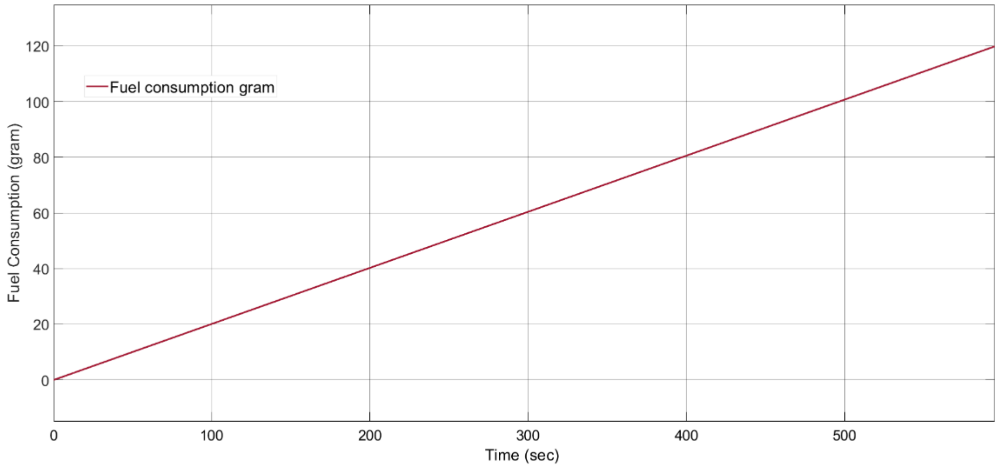


Fig 4.22. Engine Fuel Consumption in series hybrid vehicle over one MIDC cycle

### 4.8.2 Parallel Hybrid Drivetrain

In this we implement parallel hybrid powertrain in MATLAB by using simscape, simulink, powertrain blockset libraries.We test our result on Modified Indian Drive Cycle(MIDC).

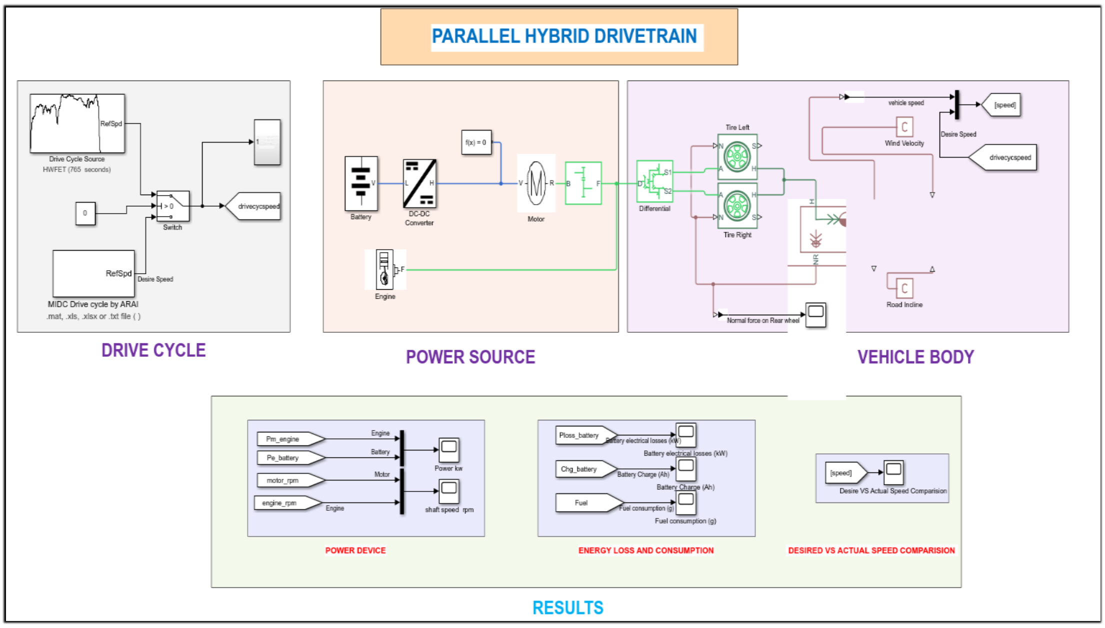


Fig 4.23. Modelling parallel hybrid drivetrain over in MATLAB

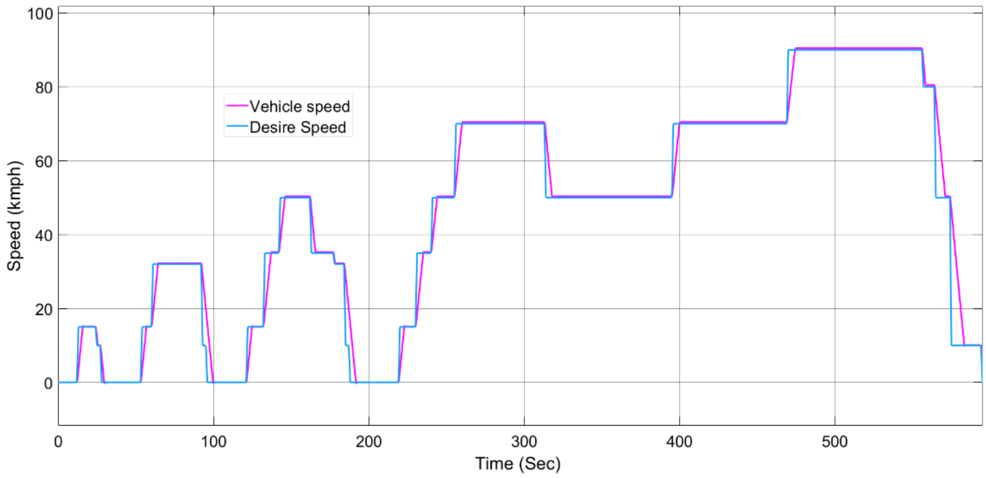


Fig 4.24: Vehicle following MIDC Speed Profile

The vehicle will experience a number of driving scenarios that replicate ordinary real-world driving during a MIDC cycle. These circumstances include acceleration, steady-state driving, and deceleration. For the vehicle to move when accelerating, it needs a strong power output from both the battery and the engine. In this instance, the power output from the engine and battery will be combined to satisfy the vehicle's power requirements.

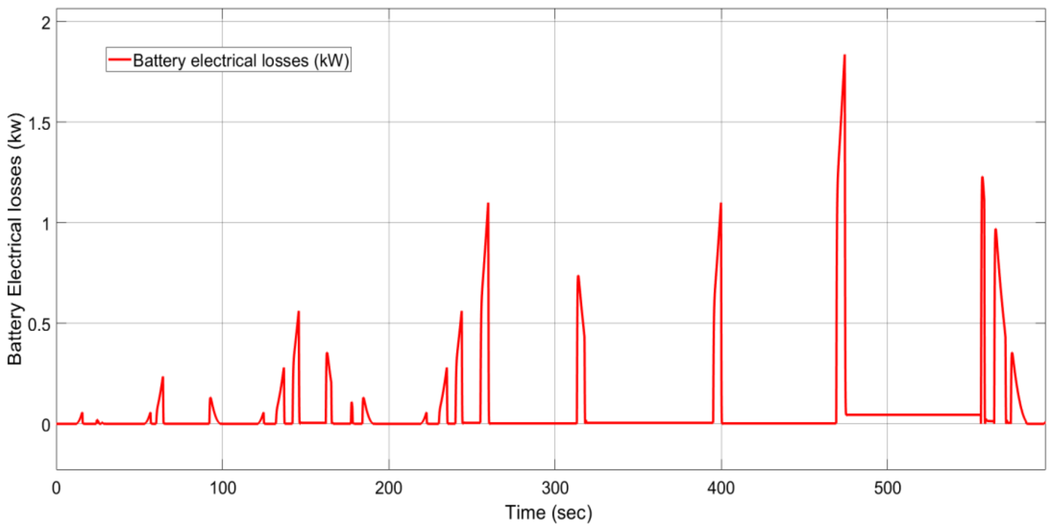


Fig 4.25: Battery Electrical Losses in parallel hybrid vehicle over one MIDC cycle

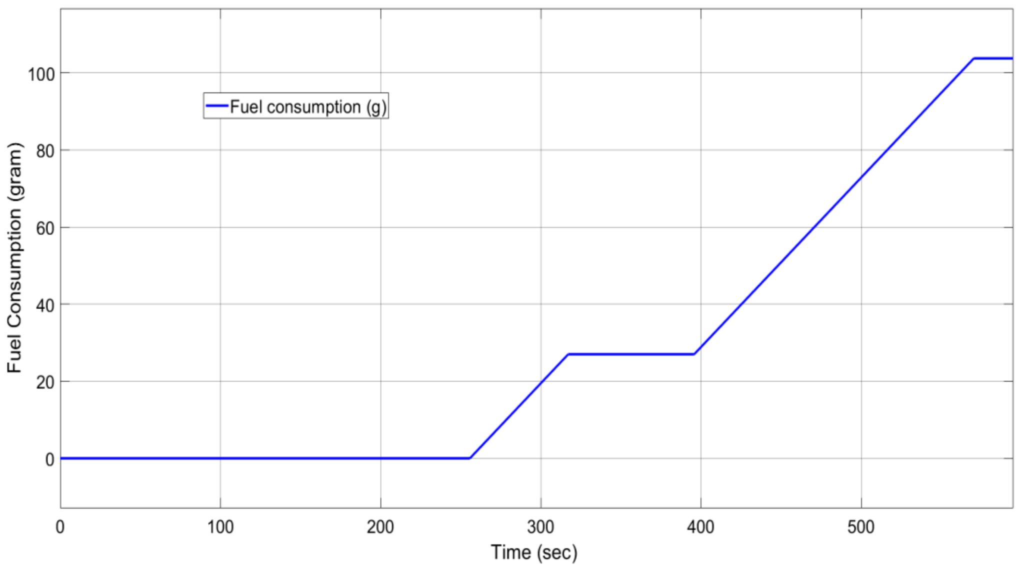


Fig 4.26: Engine Fuel Consumption in parallel hybrid vehicle over one MIDC cycle

The amount of gasoline used by the ICE during the MIDC cycle will depend on how frequently and at what power it is used to directly drive the wheels as well as how frequently it is used to recharge the batteries. When the car is moving slowly or cruising, the electric motor frequently powers the wheels directly, with the ICE typically only being required to refuel the battery. However, the ICE may be used to directly power the wheels during acceleration or high-speed driving to supply the necessary power.

The efficiency of the internal combustion engine (ICE) and the electric motor and generator used to replenish the battery will all have an impact on how much gasoline the parallel hybrid car uses.

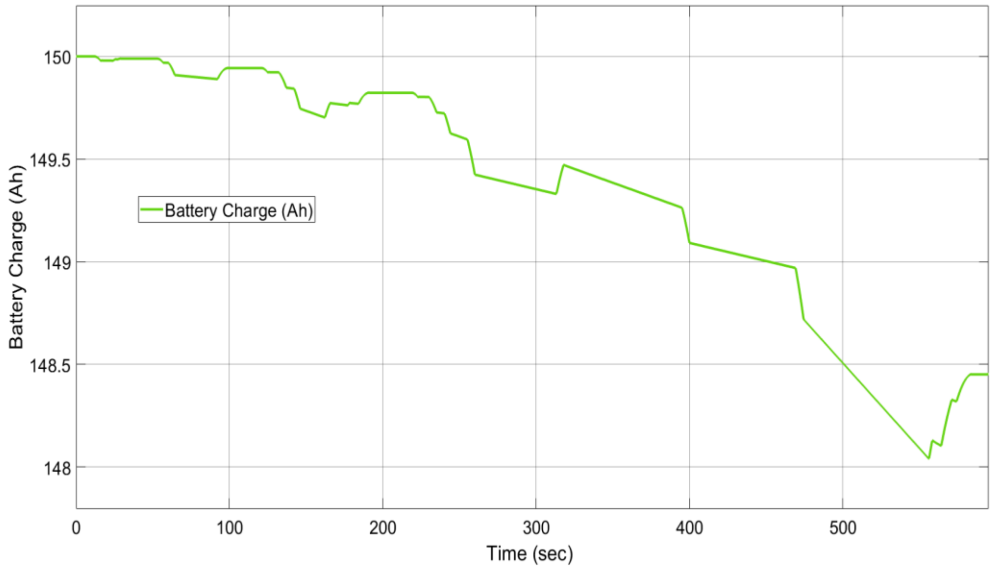


Fig 4.27: Battery Charge (Amphere-hour) over one MIDC cycle

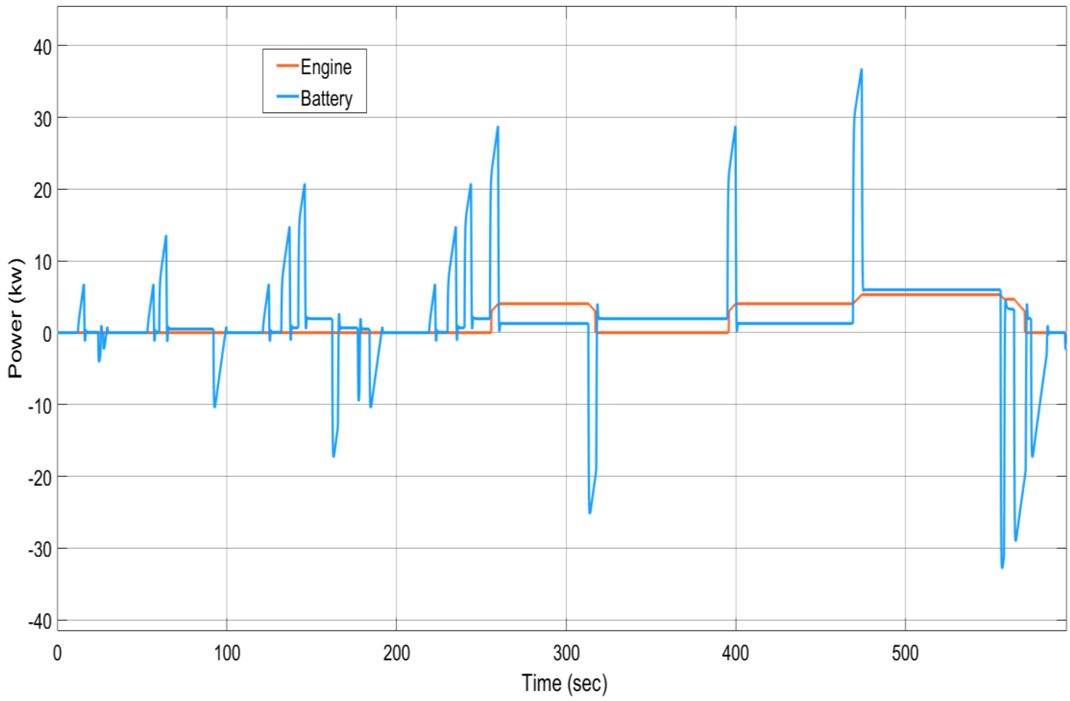


Fig 4.28: Battery and Engine Power over one MIDC cycle in parallel drivetrain

A parallel hybrid electric vehicle's battery and engine power variations during a MIDC cycle might be depicted on the resulting graph. It would shed light on how much energy the car uses and how much power it produces as well as how the battery and engine perform under various driving circumstances.

### 4.8.3 TATA NEXON Electric Vehicle based on DC MOTOR

An integrated 30.2 kWh lithium-ion battery powers the Nexon EV and 94.5 KW DC motor. Motor is control by PID controller by using feedback loop. We feed MIDC cycle and on simulation we get different result like variation of normal force on front and rear wheel, difference in desire vs actual speed, state of charge over one drive cycle of 595 sec, voltage and current flowing into the motor. Weight of our vehicle is same as nexon ev which is 1400 kg.

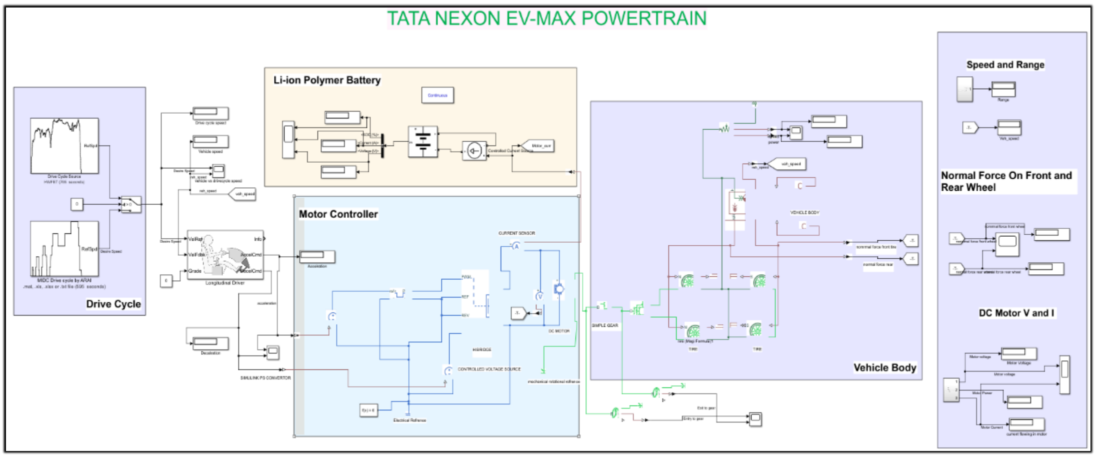


Fig 4.29: MATLAB Model of EV based on TATA NEXON

| | |
|---|---|
| Weight | 1400 kg |
| Motor | DC (94.5 KW) |
| Simple Gear Ratio | 4:1 |
| Frontal Area | 2.4 m^2 |
| Coefficient of Friction | .013 |
| Coefficient of Drag | .25 |
| Air Density | 1.18 kg/m^3 |
| Horizontal distance from CG to front axle | 1.1 m |
| Horizontal distance from CG to rear axle | 1.3 m |
| CG height above ground | .5 m |

Table 4.3: Vehicle parameter require for simulation

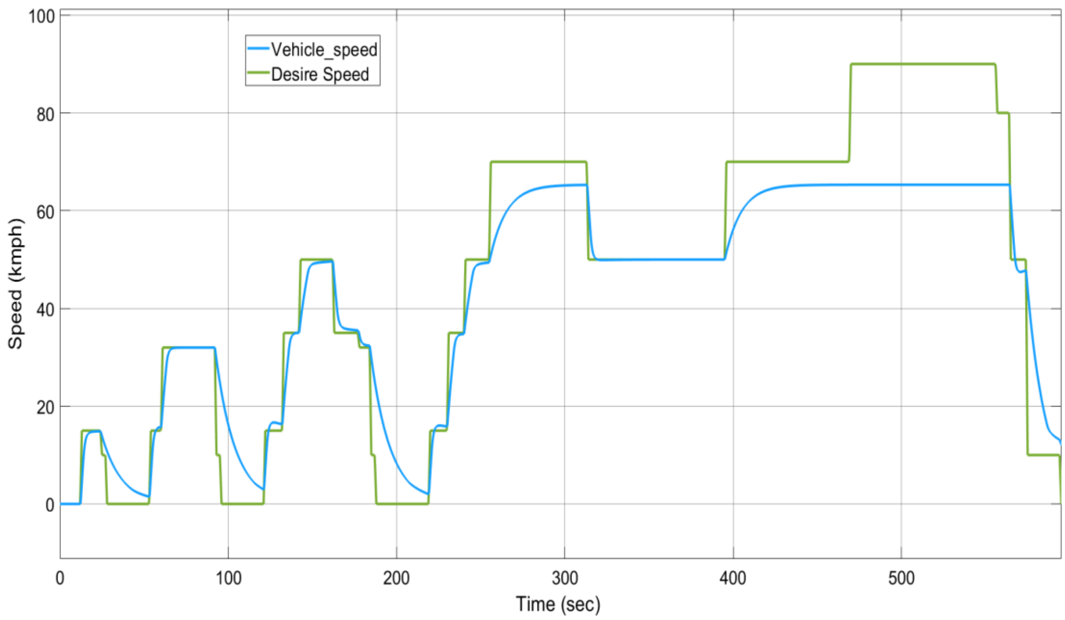


Fig 4.30: Vehicle following MIDC Speed profile

The vehicle is put through a set speed and load cycle during this test, simulating typical driving circumstances in India.The exact battery and motor system of the vehicle, the operator's driving style, and the test conditions are only a few of the variables that can affect the voltage, current, and state of charge for an electric car during the MIDC cycle.

The voltage and current of the electric vehicle will often fluctuate throughout the MIDC cycle as it speeds up, slows down, and maintains a constant speed. Voltage will fall when the vehicle picks up speed due to an increase in current demand. The motor of the car will function as a generator during braking and regenerative acceleration, raising the voltage as power is transferred back to the battery.

During the MIDC cycle, the battery's state of charge will also change; it will drop as energy is extracted from the battery and rise as regenerative braking occurs. The battery and motor system of the vehicle in question, as well as the operator's driving style, will determine the precise rate of change.

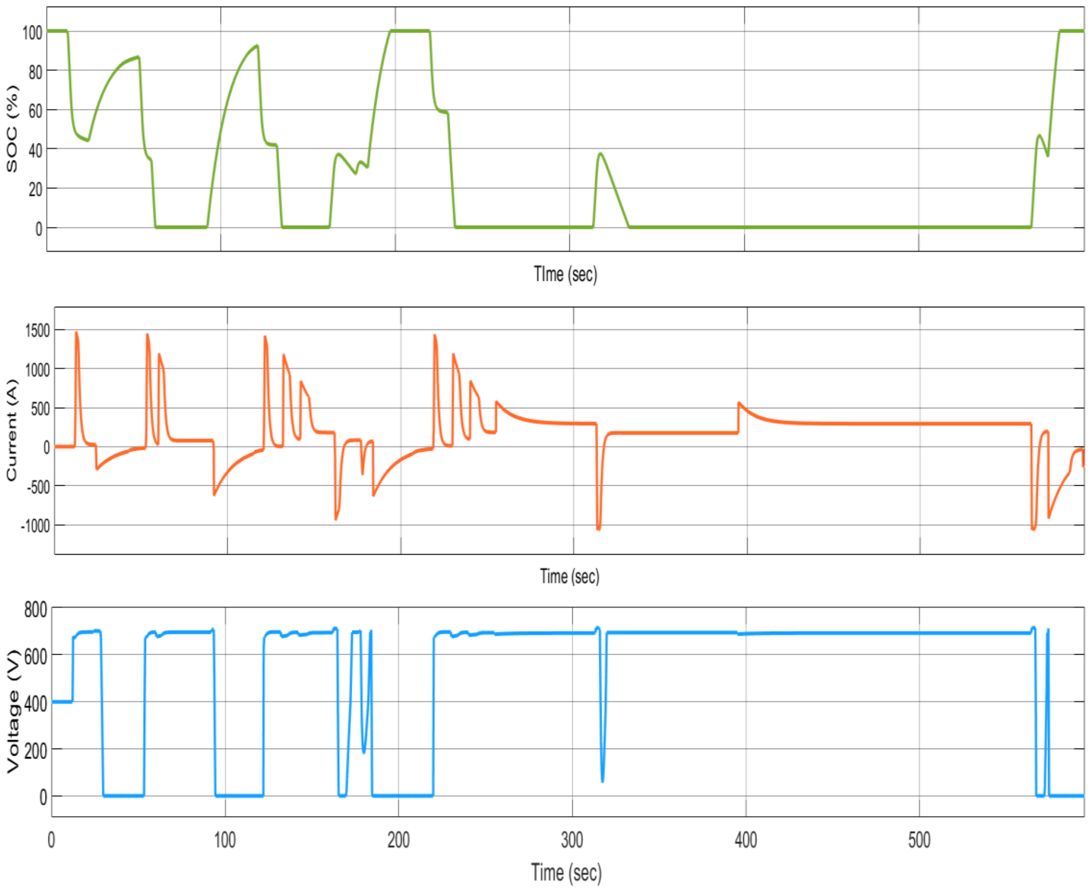


Fig 4.31: Li-Ion Battery SOC, Current, Voltage Over a Cycle

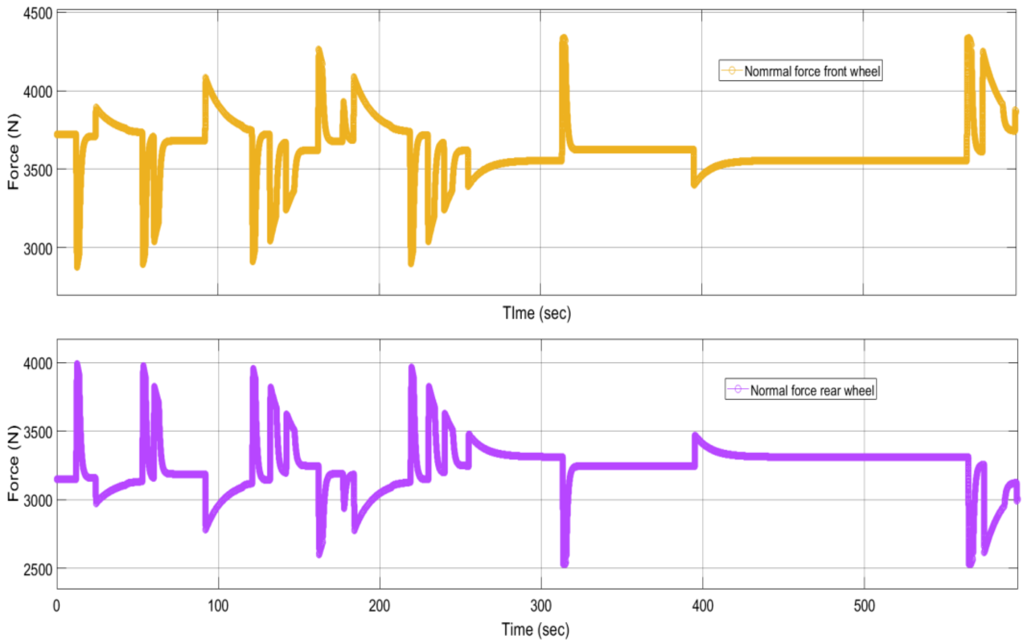


Fig 4.32: Variation of Normal force on front and rear wheel

The variation of normal force on the front and rear wheels of a vehicle depends on the weight distribution of the vehicle, the position of the center of gravity, and the motion of the vehicle (braking, accelerating, or turning).

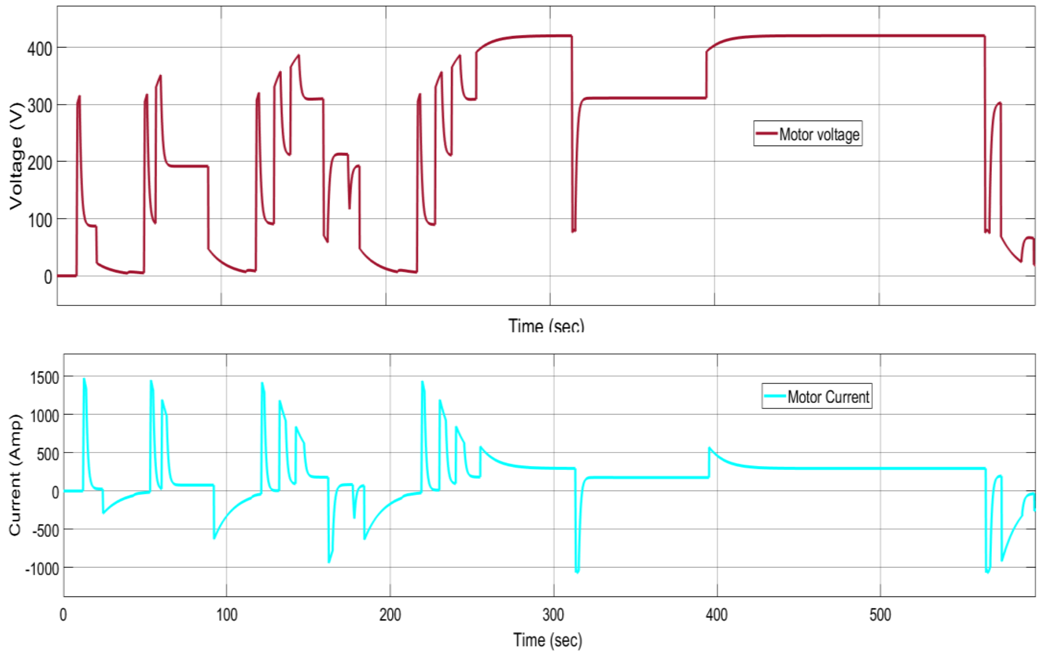


Fig 4.33: Variation of Voltage and Current inside the DC Motor

The voltage and current inside the DC motor can be seen and studied by altering the input voltage and load resistance in the simulation. By altering the voltage and current numbers, the simulation may also be used to maximise the DC motor's performance and produce the ideal speed and torque characteristics for the electric car.

The simulation can be used to examine other facets of the electric vehicle system, including battery performance, controller behaviour, and power management techniques, in addition to replicating the voltage and current inside the DC motor.

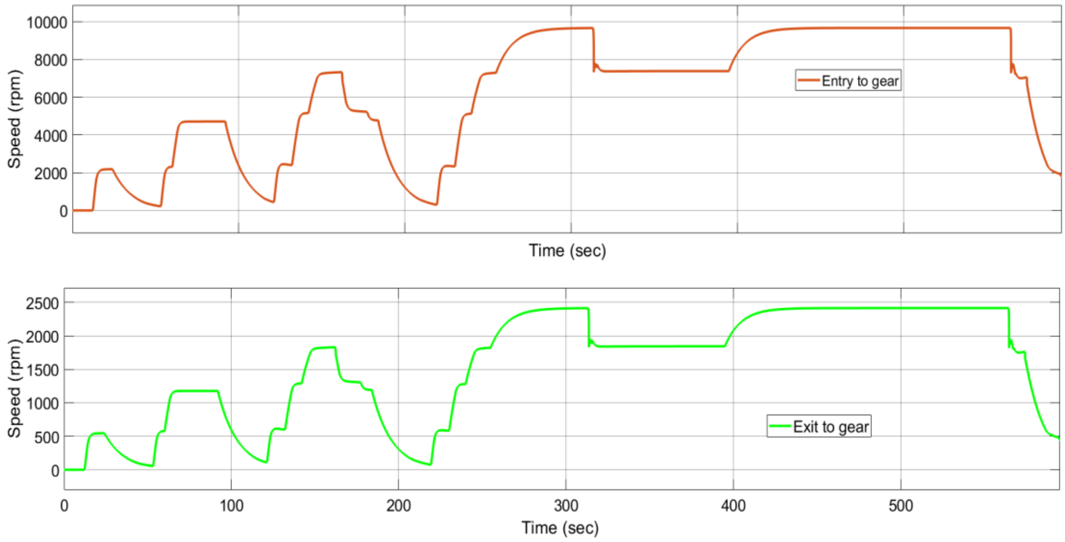


Fig 4.34: Simple gear with gear ratio 4

A fixed ratio gear directly connects the motor to the wheels in a single fixed gear electric vehicle (EV). The link between the motor speed and the wheel speed is determined by the gear ratio. The wheels spin quicker but with less torque when the motor turns more quickly. On the other hand, the wheels move more slowly but with more torque at lower motor speeds.

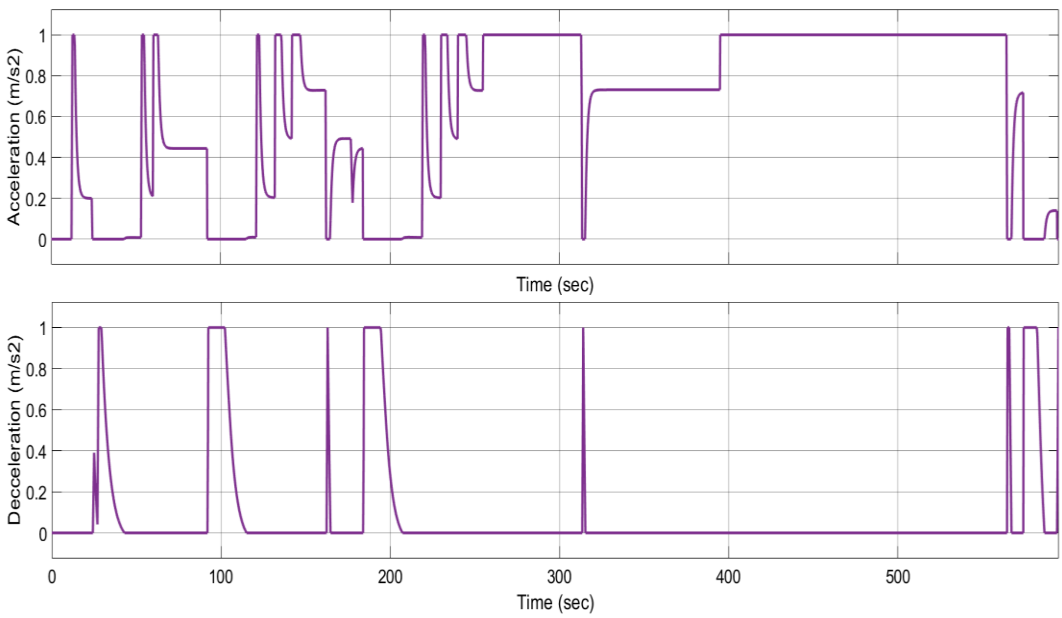


Fig 4.35: Acceleration/Decceleration (m/s2)

### 4.8.4 MATLAB MODEL of TATA NEXON Based On BLDC Motor

A Motor & Drive block is used in the model to create a closed-loop electric all-terrain vehicle. Because there are no mechanical commutations in BLDC motors, they require less maintenance. Due to their low inertia rotor, BLDC motors also have a faster dynamic reaction than induction motors. BLDC motors have all the advantages listed above, and they are becoming increasingly popular due to their impressive uses in robotics, automotive, and industrial applications. As a result, there is a great demand for a procedure for building a low-cost and effective BLDC motor drive that includes novel approaches, tools, and circuits.

To simulate closed-loop control for a BLDC vehicle in MATLAB Simulink, follow these steps:

Model the BLDC motor and the vehicle dynamics: You can model the BLDC motor using a mathematical model that describes the relationship between the input voltage and the output speed or position of the motor. You can also model the vehicle dynamics, such as the tire friction, vehicle mass, and aerodynamic drag.

Implement the control algorithm: There are several control algorithms that can be used for BLDC vehicles, such as proportional-integral-derivative (PID) control, sliding mode control, and model predictive control. You can implement the control algorithm in MATLAB Simulink using blocks such as the PID Controller block, State-Space block, or Transfer Function block.

Establish the feedback loop: In closed-loop control, the output of the system is fed back to the input to adjust the input and achieve the desired output. You can establish the feedback loop in MATLAB Simulink using a feedback block.

Simulate the system: Once you have modeled the system, implemented the control algorithm, and established the feedback loop, you can simulate the system in MATLAB Simulink. You can vary the input, such as the reference speed or position, to observe the response of the system and adjust the control algorithm to achieve the desired response.

Analyze the results: After simulating the system, you can analyze the results to determine the performance of the control algorithm. You can observe the response of the system, such as the settling time, rise time, and overshoot, and adjust the control algorithm to optimize the performance.

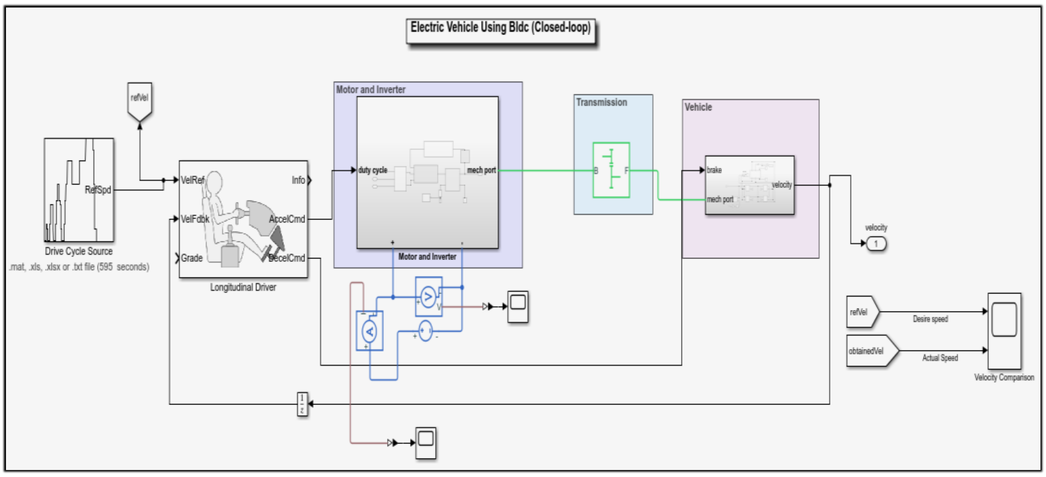


Fig 4.36: Closed loop control BLDC vehicle (TATA NEXON)

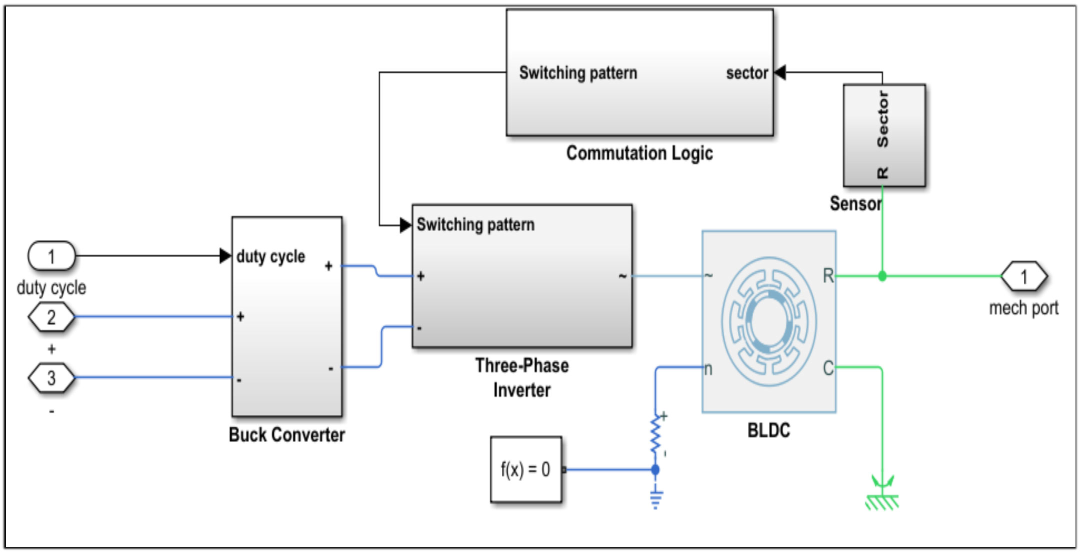


Fig 4.37: Implimentation of BLDC Motor With Controller In MATLAB

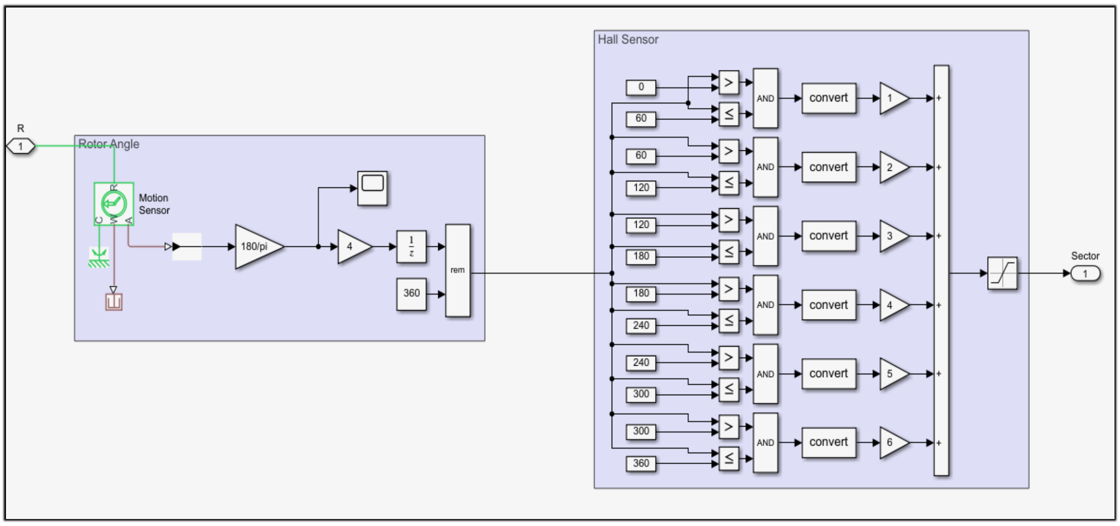


Fig 4.38: Hall Sensor Logic Design in MATLAB

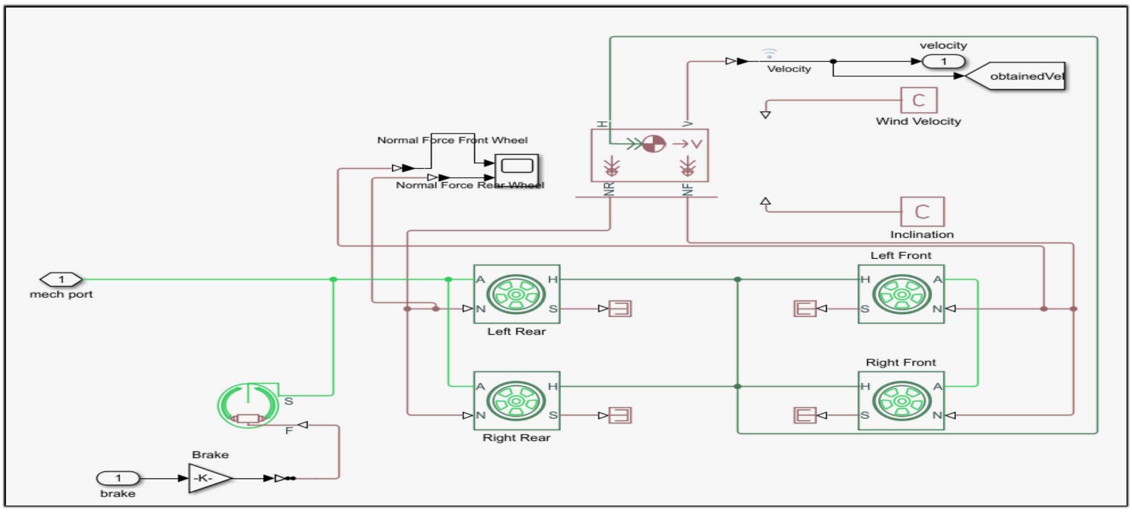


Fig 4.39: Vehicle body in MATLAB Model using simscape

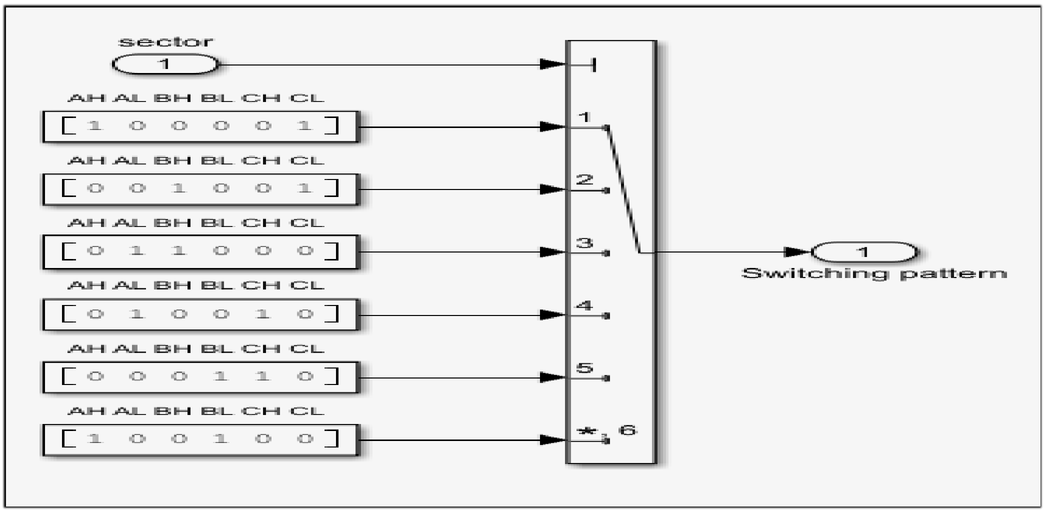


Fig 4.40: Commutaion logic Model in MATLAB

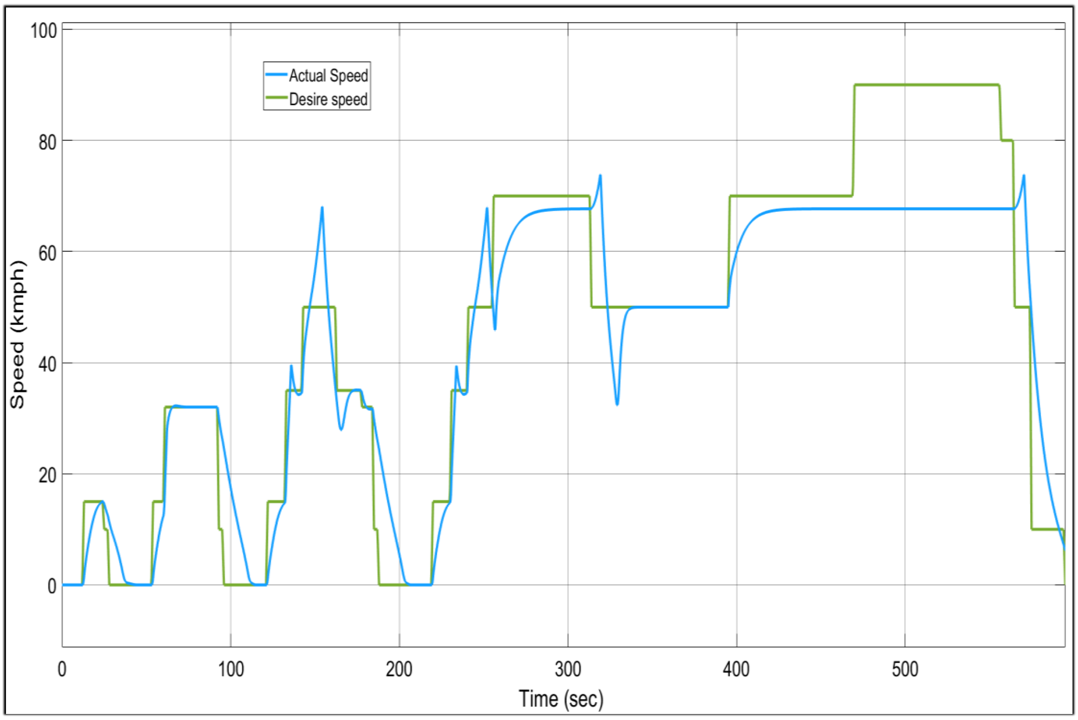

Fig 4.41: Desire VS Actual Speed Comparison on MIDC Cycle

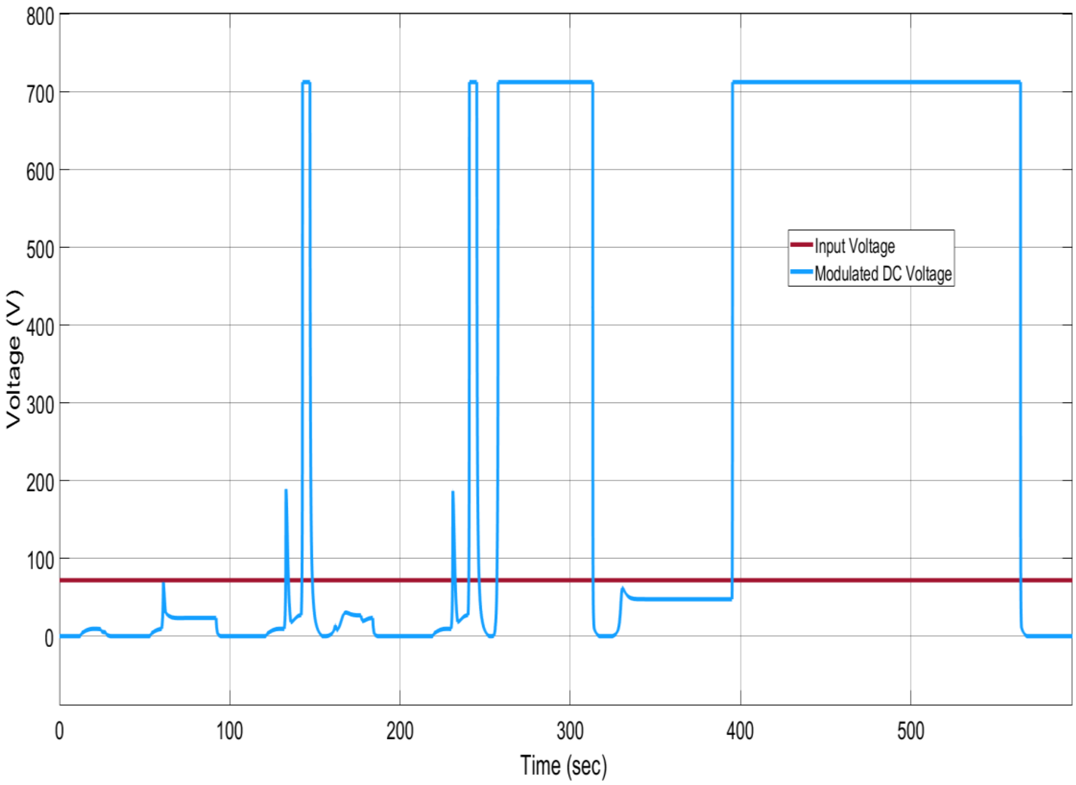

Fig 4.42: Modulated DC voltage by BUCK-BOOST Convertor

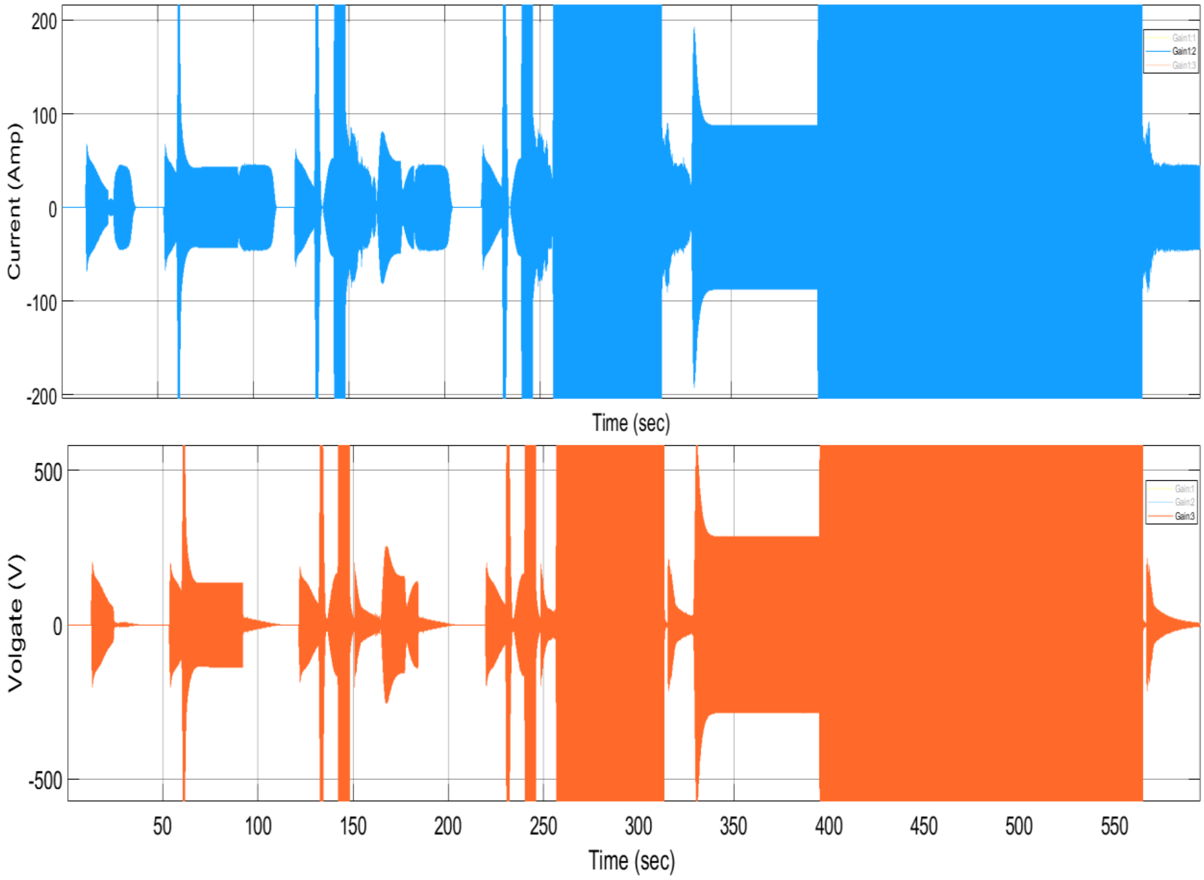


Fig 4.43: Three-Phase Current and Voltage by Controller

# CHAPTER 5 Conclusion and future scope

## 5.1. Conclusion

By comparing the simulation results for different types of traction motors, we can evaluate the relative benefits and drawbacks of each motor design in terms of performance, efficiency, and cost. This information can be used to guide the design of future electric vehicles and improve their overall performance and sustainability.

| Specification | PMSM | BLDC | INDUCTION | DC |
|---|---|---|---|---|
| Energy Efficiency(Wh/km) | 90 | 100 | 120 | 140 |
| Battery (KWh) Required for 250 km Range | 28.12 | 31.25 | 37.25 | 43.75 |
| Motor Capacity(KW) Based on Peak power | 95 | 105.5 KW | 112 KW | 158 KW |
| Control Algorithm Used | Field-Oriented Control | Six-Steps Commutation | Vector Control | PWM Control |

Table 5.1: Simulation Result of TATA Nexon On Different Motor

- The most effective traction motor is the PMSM IPM (Interior Permanent Magnet). PMSM (IPM) > PMSM (SPM) > BLDC > Induction > DC is the decreasing order of traction motor efficiency.
- Induction motors function well at high speeds or on highways but are less effective at low speeds in cities.
- At the same battery size, a higher-efficiency motor gives us a greater vehicle range.
- Following various simulations on various vehicles to design the powertrain, the following voltages are generally chosen:

| Voltage | Type Of Vehicle |
|---|---|
| 48-72 V | 2-Wheeler, 3-Wheeler |
| 350 V | Car, Pickup |
| 750 V | Buses, Truck |

Table 5.2: Voltage selection for powertrain among different vehicles

- With increase in Coefficient of friction and coefficient of drag efficiency (Wh/km) increases linearly.
- Capacity of a traction motor for a vehicle largely depends on maximum speed of vehicle. Same vehicle on simulation tested to get different maximum speed.For a 4-W sedan having weight of 1400 kg at a slope of 5 degree with frontal area 2.5 m2 and coefficient of friction .013.

| **Speed** | **Power of Motor Require** |
|---|---|
| 50 kmph | 10 KW |
| 60 kmph | 13 KW |
| 70 kmph | 18.5 KW |
| 80 kmph | 25 KW |

Table 5.3: Requirement of Traction motor with Speed

- Due to its low cost and secure low voltage, 48-V hybrids fall under the mild hybrid category, which is well-liked in Indian automobiles. This system's purpose is to start, halt, and regenerate with 15–25 KW of electrification.This mild hybrid technology included in the Maruti Suzuki S-Cross, Baleno, and Grand Vitara reduces $CO_2$ emissions by 20% and fuel consumption by 15%.

## 5.2. Future scope

As more and more nations adopt strict pollution standards and strive for cleaner mobility options, the future potential of electric and hybrid electric vehicles (HEVs) is highly promising. For modelling the powertrain systems of electric and hybrid vehicles, MATLAB is a potent tool. Here are some potential applications of MATLAB for modelling electric and hybrid electric vehicle powertrain systems:

Battery Modeling: MATLAB can be used to model the behavior of batteries in electric vehicles. This includes simulating battery charge and discharge cycles, estimating battery life and performance, and evaluating the impact of different charging and discharging strategies on battery life.

Power Electronics: MATLAB can also be used to simulate the behavior of power electronics components like DC-DC converters, inverters, and motor controllers. This helps in optimizing the design of power electronics systems for electric and hybrid electric vehicles.

Motor Modeling: MATLAB can be used to model the behavior of electric motors used in electric and hybrid electric vehicles. This includes simulating the motor torque-speed characteristics, analyzing the impact of motor design parameters on performance, and optimizing the design of the motor for a given application.

Hybrid Powertrain Modelling: The behaviour of hybrid powertrains in hybrid electric vehicles can be simulated using MATLAB. This entails optimising the control schemes for the hybrid powertrain as well as modelling the behaviour of the internal combustion engine, electric motor, and battery pack.

The future of electric and hybrid vehicles is, all things considered, rather promising, and MATLAB can be quite useful in designing and improving the powertrain systems of these vehicles. The necessity for precise and effective powertrain simulations using tools like MATLAB will only grow in the future due to the rising need for cleaner transportation solutions.

## References


1. Liu, H., Hu, X., & Jiang, J. (2017). Modeling and simulation of electric vehicle powertrain system using MATLAB/Simulink. Applied Sciences, 7(10), 1091.

2. Kim, T., Lee, Y., & Kim, K. (2018). Development of a dynamic model of a hybrid electric vehicle powertrain system in MATLAB/Simulink. Energies, 11(3), 604.

3.Zhang, Y., Wang, X., Chen, H., & Chen, J. (2020). Modeling and simulation of a series-parallel hybrid electric vehicle powertrain in MATLAB/Simulink. Energies, 13(12), 3207.

4.Bian, Y., Huang, J., Song, L., & Chen, W. (2018). Study on the modeling and simulation of the powertrain system for a pure electric vehicle based on MATLAB/Simulink. IEEE Access, 6, 61384-61392.

5.Li, H., Li, Y., Li, B., Li, S., & Li, J. (2020). Dynamic modeling and simulation of powertrain system for hybrid electric vehicle using MATLAB/Simulink. Journal of Energy Storage, 29, 101349.

6.Yang, L., Zhang, Y., Chen, H., & Wu, B. (2019). Modeling and simulation of a plug-in hybrid electric vehicle powertrain based on MATLAB/Simulink. Energies, 12(5), 787.

7.Li, Y., Zhang, L., & Li, K. (2017). Design and simulation of hybrid electric vehicle powertrain based on MATLAB/Simulink. IOP Conference Series: Earth and Environmental Science, 99(1), 012128.

8._ang, H., Zhu, J., Cao, X., & Xiong, Y. (2019). Dynamic modeling and simulation of an electric vehicle powertrain system based on MATLAB/Simulink. Journal of Control Science and Engineering, 2019, 1-12.