

CERTIFICATION

This is to certify that this work is original and was carried out by the afore-listed students under the supervision of the project supervisor.

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DEDICATION

This project is dedicated to God for provision and faithfulness during the process. We extend our dedication to our supervisor, and our parents, for their support and love during this project and throughout our lives.

ACKNOWLEDGEMENTS

We are grateful to God and our parents for their support, both financially and emotionally, throughout the completion of this project. We also extend our appreciation to our supervisor, Dr. Collins Chike KwasiEFFah, for his guidance and contributions to the project. We express our gratitude to the department of Mechanical Engineering, friends, and colleagues. We are grateful for everyone's contribution

Contents

CERTIFICATION	ii
DEDICATION	iii
ACKNOWLEDGEMENTS	iv
List of Figures	viii
List of Abbreviations	x
Abstract	xii
Chapter 1	1
1.1 Background to the Study.....	1
1.2 Problem Statement.....	2
1.3 Aim and Objectives	2
1.4 Significance of the Study.....	3
1.5 Scope and Limitations	3
1.6 Methodology	4
2.1 Overview.....	5
2.2 Brief History of HEVs	7
2.3 Classification of Hybrid Electric Vehicles	7
2.3.1 Classification Based on Hybridization	8
2.3.2 Classification Based on Drivetrain Architecture	10

2.3.3 Classification Based on the Nature of the Power Source.....	14
2.4 Components of a Hybrid Electric Vehicle.....	16
2.4.1 Prime Movers.....	16
Applications.....	17
Fuel and oxidizer types.....	25
Hydrogen.....	26
2.4.2 Electric Motor.....	32
2.4.3 Motor Controller.....	42
2.4.4 Energy Storage System.....	43
2.5 Go-Kart.....	46
2.6 Components of a Go-Kart.....	46
2.6.1 Chassis.....	47
2.6.2 Steering.....	47
2.6.3 Power System.....	50
2.6.4 Drivetrain.....	50
2.6.5 Braking System.....	50
2.7 Vehicle Dynamics.....	50
2.8 Review of Related Literature.....	53
CHAPTER THREE.....	56

3.0 METHODOLOGY	56
3.1 Design Flow Chart	56
3.2 Concept Design.....	57
3.3 Modelling of Regenerative Breaking.....	59
3.4 Preliminary Analysis.....	77
CHAPTER FOUR.....	80
4.1 Simulation results When Vehicle is in the electric Mode	80
4.2 Simulation results When Vehicle is in the IC Mode	86
Chapter 5	89
5.1 Conclusion	89
5.2 Recommendation	Error! Bookmark not defined.
5.3 References.....	Error! Bookmark not defined.

List of Figures

- Figure 2-1: Series hybrid drivetrain structure
- Figure 2-2: Parallel hybrid drivetrain structure
- Figure 2-3: Series-parallel hybrid drivetrain structure
- Figure 2-4: Standard (Conventional) and Plug-in hybrid vehicles
- Fig 2-5: An illustration of several key components in a typical four-stroke engine
- Fig 2-6: Electric motor
- Fig 2-7: Electric motor rotor (left) and stator (right)
- Fig 2-8: Classifications of electric motors
- Figure 2-9: Equivalent circuit for a DC motor
- Figure 2-10: Ackermann steering geometry
- Figure 2-11: Diagram labeling the action of a four-wheeler making a turn
- Figure 2-12: Free body diagram of a vehicle accelerating up an inclination
- Fig 3-1: The Design Flow Chart
- Fig 3-2: The Conceptual Design
- Fig 3-3: Hybrid Electric Vehicle
- Fig. 3-4: vehicle on electric mode(simulation)
- Fig 3-5: Motor Parameters adjusted to that of the actual Dc motor
- Fig 3-6: Battery Parameter and discharge curve
- Fig 3-7: Vehicle Body Parameter
- Fig 3-8: Modal Drive cycle velocity graph
- Fig 3-9: Simulation of vehicle driven by ICE
- Fig 3-10: Flow process of the simulation
- Fig 3-10: Flow process of the simulation

Fig 3-11: Block parameters for ic-engine

Fig 3-12: The Battery input parameters

Fig 3-13: The throttle input signal

Fig 4-1: The Velocity-Time graph of the UFFa_19 series in a particular location

Fig 4-2: The State of Charge against Time

Fig 4-3: The State of Charge against Time (showing the batter life saved)

Fig 4-4: The Battery Voltage against Time

Fig 4-5: The Velocity against Time

Fig 4-6: The Battery state of Charge against Time

Fig 4-7: The Current drawn from battery against Time

Fig 4-8: The Battery Voltage against Time

Fig 4-9: The Throttle Input SInal

Fig 4-10: The Battery state of Charge

Fig 4-11: The Current against Time

Fig 4-12: The Battery Voltage against Time

Fig 4-13: Fuel Consumption During Regenerative Breaking against Time

List of Abbreviations

CAD – Computer Aided Design

FEA – Finite Element Analysis

HEV – Hybrid Electric Vehicle

ZEV – Zero Emission Vehicles

HC – Hydro carbon

ICEV – Internal Combustion Engine Vehicles

ICE – Internal Combustion Engines

IC – Internal Combustion

EV – Electric Vehicle

HF – Hybridization Factor

μ HV – Micro Hybrid Vehicle

MHV – Mild Hybrid Vehicle

FHV – Full Hybrid Vehicle

SHEV – Series Hybrid Electric Vehicle

PHEV – Parallel Hybrid Electric Vehicle

SPHEV – Series-Parallel Hybrid Electric Vehicle

SOC – State of Charge

ESS – Energy Storage System

CI – Compression Ignition

SI – Spark Ignition

TDC – Top Dead Centre

BDC – Bottom Dead Centre

AC – Alternating Current

DC – Direct Current

BLDC – Brushless DC

UDDS – Urban Dynamometer Driving Schedule

HWFET –Highway Fuel Economy Test

EM – Electric Motor

PWD – Pulse Width Modulation

ABSTRACT

The project aims to address the environmental concerns associated with conventional internal combustion engines by developing a mini hybrid electric vehicle. The goal is to reduce emissions, fuel consumption, and noise while maintaining vehicle performance. The specific focus is on improving an already-fabricated vehicle, the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE, by introducing new features such as a brake mechanism, reverse mechanism, and bodywork. The ultimate goal is to reduce reliance on fossil fuels by using materials that can be easily gotten locally hereby increasing the overall efficiency of the vehicle.

The methodology includes two main components which are:

Designing a suitable and aesthetic bodywork for the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE using computer-aided design (CAD) software. This will involve creating detailed 3D models of the vehicle body and making sure that it meets all of the necessary safety and performance requirements. It also includes designing a regenerative braking system for the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE using MATLAB Simulink. This will involve creating a simulation of the braking system and testing it in a virtual environment to ensure that it functions as intended and can effectively capture and store energy during braking.

From the simulation results, it appears that the regenerative braking system is effective in reducing fuel consumption and increasing the battery state of charge. Specifically, it is noted that during regenerative braking, fuel consumption is

minimal, with about 43% being conserved. Additionally, the battery state of charge increases from its initial 30% to 33%. The dynamic analysis and simulation also indicate that a 750W brushless motor will be sufficient when connected in parallel to an internal combustion engine with a power rating of 1600Watts for the purpose of regenerative braking. Overall, the simulation results suggest that the regenerative braking system and the use of a brushless motor in parallel with the IC engine have the potential to significantly reduce fuel consumption and improve overall efficiency of the vehicle.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The pervasive utilization of the internal combustion engine in vehicles has brought about air pollution caused by exhaust fumes, which are the byproducts of burning fossil fuels. This releases detrimental quantities of carbon monoxide and contributes to smog. To address this issue, automobile manufacturers are shifting production towards hybrid systems and pure electric vehicles, which produce fewer emissions. Hybrid electric vehicles (HEVs) have benefits over traditional internal combustion engine vehicles (ICEVs) such as better mileage, high fuel efficiency, enhanced productivity, less dependence on petroleum, reduced noise, and less air pollution. HEVs have two sources of power: the internal combustion engine and the electric motor. These vehicles can be classified into different types based on the arrangement of their components, such as series hybrids, parallel or series-parallel hybrids, and complex hybrids. The Prius, produced by Toyota as their first hybrid car, has become one of the most popular hybrid vehicles and has paved the way for their wider adoption in society. With ongoing development, it is estimated that HEVs will become more widely used globally. Modern HEVs use technologies such as regenerative braking and start-stop systems to enhance efficiency and reduce emissions.

1.2 PROBLEM STATEMENT

Given the increasing global concern about the negative effects of global warming and the environmental impact of excessive fossil fuel emissions from traditional internal combustion engines, it is imperative for vehicle manufacturers to develop more fuel-efficient technologies that can reduce emissions from these vehicles and safeguard human health and the ozone layer. Additionally, the high cost of fuel and noise from traditional internal combustion engines also present a challenge. Hybrid electric vehicles (HEVs) are considered as a short-term or medium-term solution to these issues, as they are designed to decrease emissions, fuel consumption, and noise, while maintaining vehicle performance. Creating a mini HEV can play a crucial role in addressing these challenges. In particular, the previously built UFAA-19 SERIES HYBRID ELECTRIC VEHICLE was found to have deficiencies such as lack of regenerative braking system and an unappealing body design, which when improved upon, will lead to enhanced performance

1.3 AIM AND OBJECTIVES

The objective of this project is to enhance the performance of the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE by incorporating a regenerative braking system and revamping the design of the vehicle's bodywork. This will aid in reducing dependency on fossil fuels and making use of locally sourced materials.

The objectives are:

- Developing a regenerative braking system design for the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE.

- Creating an attractive body design for the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE.

1.4 SIGNIFICANCE OF THE STUDY

This project is essential for the transportation energy sector, both worldwide and locally, which currently heavily depends on fossil fuels. The small hybrid electric vehicle developed in this undertaking has a remarkable application in the transportation energy industry.

1.5 SCOPE AND LIMITATIONS

This project covers:

- Designing an attractive and appropriate bodywork for the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE.
- Researching and designing a regenerative braking system for the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE, with a focus on its potential use in the Nigerian transportation energy industry

1.6 METHODOLOGY

The methodology for this project comprises:

1. Designing an attractive and appropriate body work for the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE using CAD.
2. Designing a regenerative braking system for the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE using matlab simulink.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

A hybrid vehicle utilizes multiple forms of power to operate. These vehicles often incorporate both a traditional internal combustion engine and an electric motor for propulsion. The electric motor is particularly effective at providing torque, while the combustion engine is better suited for maintaining high speeds. By utilizing both power sources in a coordinated manner, hybrid vehicles can achieve greater energy efficiency than traditional vehicles that solely rely on internal combustion engines. This results in improved fuel efficiency and reduced fuel consumption. Hybrid electric vehicles (HEVs) can also perform one or more other functions that improve energy efficiency. these includes:

- engine start and stop while idling.
- energy recovery during regenerative braking
- torque support through electric power.
- electric propulsion
- Recharge of battery (from the operation)
- Recharge of battery (from the power network)

The majority of road transportation is driven by traditional internal combustion engine vehicles, which when used on a large scale can have significant impacts on society and the environment. These impacts involve:

- Decreased atmosphere purity owing to exhaust exhalations
- Introduction of heat-trapping gases into the air
- Respiratory problems caused by air pollutants from exhaust emissions.

- the sound of an engine running

In Nigeria, road transportation is the primary mode of transport and the high volume of vehicles on the roads results in significant environmental emissions. With increasing awareness of environmental issues and the implementation of policies to decrease emissions, there is hope that the quantity of non-ICEVs will grow in the future. Electric vehicles are one potential solution as they produce less noise and no exhaust fumes, however, Nigeria currently faces challenges such as electricity instability and the lack of long-distance battery technology. Hybrid electric vehicles present a compromise, utilizing natural fossil fuels while reducing emissions by up to 31% and greenhouse gas emissions by 339g/mile. Other advantages of HEVs include:

- Less dependence on fossil fuels
- engines for power transmission
- Eco-friendly due to a decrease in carbon footprint on the environment.
- Greater distance traveled

One potential drawback of hybrid electric vehicles is that there are certain limitations that need to be addressed in order to increase widespread adoption. These include:

- Rising costs for maintenance and fix due to a lack of qualified technicians in the region.
- More expensive than conventional gasoline-powered vehicles.
- There is a potential for accidents associated with the high voltage in batteries.
- They have less power in comparison to traditional gasoline-powered vehicles.
- They have not yet been mass-produced by various manufacturers globally.

2.2 BRIEF HISTORY OF HEVS

In the early 21st century, there was an issue with the internal combustion engines producing excessive amounts of pollution. The idea for the first hybrid car was inspired by a Viennese coach builder named Jacob Lohner, who believed that gas-powered cars were too loud and smelly. The primary objective of constructing a hybrid vehicle was to solve this issue, and it started as a completely electric automobile fashioned by Lohner and Porsche. They wanted to combine Porsche's electric wheel-hub motor, a battery-driven motor that could fit inside the wheel hub, with Lohner's coach. The wheel center was subsequently altered to be driven by an internal combustion motor that operated a generator for restoring the power cells. Porsche became involved in the undertaking and they eventually released the Lohner-Porsche Elektromobil, of which about 300 were sold. Nonetheless, the vehicle never achieved widespread fame and hybrids were mostly neglected until the 1960s, when the United States began to center on diminishing contamination from automobiles. Policies were put in place to reduce exhaust emissions and funding was provided for research on emission control. Numerous automakers created their own solutions, such as GM with the GM 512 in 1968, Audi with the Audi Duo in 1989, and Honda with the Honda Insight in 1999, but none achieved the same level of success as the Toyota Prius. The Prius was first presented in Japan in 1997 and released in the United States in 2000. It was a commercial success and encouraged additional manufacturers to enter the hybrid market by 2007, when it had sold over a million units.

2.3 CLASSIFICATION OF HYBRID ELECTRIC VEHICLES

Based on a few characteristics, hybrid electric vehicles can be divided into three groups.

1. According to level of hybridization.
2. According to layout of the powertrain system.
3. According to type of energy source utilized.

2.3.1 Classification according to Level of Hybridization

Hybridization of an electric vehicle refers to how much power is being supplied by an additional source, like an internal combustion engine, in addition to the electric motor. The hybridization factor is a ratio that shows the proportion of power coming from the electric motor compared to the vehicle's entire power input. In mathematics, it can be written as:

$$\text{Hybridization factor, } HF = \frac{\text{Motor power}}{\text{Motor power} + \text{Engine power}} \quad 2.1$$

Based on the amount of power supplied by a secondary source in addition to the electric motor, hybrid electric vehicles can be categorized into different types. (i) Micro hybrid, (ii) Mild hybrid, and (iii) Full hybrid (Vidyanandan 2018)

Micro Hybrid (μ HV): Micro hybrids are a type of hybrid vehicle that feature energy management functions such as idle start/stop. They are considered to be the least electrified among the three types of hybrid vehicles. The idle start/stop function is enabled by a starter motor with a rating of 12V and 3-5kW. When the driver starts or stops the car, these motors automatically turn the internal combustion engine on or off, saving fuel. They do not actually drive the car. In addition to powering various accessories like power steering and air conditioning, the electric motor also assists in supplying electricity to the batteries during

regenerative braking. Micro hybrids offer energy savings of 3–10% and a hybridization level of 5–10%. The Mercedes Smart is a well-known example of a micro hybrid (Vidyanandan 2018).

Mild Hybrid (MHV): Mild hybrids are a type of hybrid vehicle that utilizes an electric motor with a rating of 60 to 200V and 7 to 15kW. They perform idle start and stop functions and power generation via regenerative braking, much like micro hybrids. Additionally, they give the internal combustion engine more torque when the engine is accelerating and more power is required. Since the internal combustion engine is used for most of its drive cycle, the hybridization factor is relatively low, ranging from 10-30% with energy savings of 20-30%. Honda Civic and Honda Insight are two examples of mild hybrid electric vehicles. (Vidyanandan 2018).

Full Hybrid (FHV): . Full hybrids are a type of hybrid vehicle that have the capability to operate solely on electric mode. They are equipped with large electric motors, with a voltage capacity of 200-600V and 30-50kW. These vehicles typically have energy savings of 30-50%. The Toyota Prius is an illustration of a full hybrid car.

Table 2-1 presents a summary of the various characteristics of hybrid electric vehicles according to their level of hybridization. Although regenerative braking is a frequent feature in HEVs, due to their low hybridization factors, micro and mild hybrids are unable to fully convert the kinetic energy of motion into electrical energy. In general, a vehicle's hybridization factor must be at least 40% in order to properly recover braking power (Vidyanandan 2018).

Hybrid Type	Micro Hybrids	Mild Hybrids	Full Hybrids
IC engine	Conventional	Downsized	Downsized
Motor power	3 to 5kW	7 to 15kW	30 to 50kW
Motor voltage	12V	60 to 200V	200 to 600V
Hybridization factor	< 10%	10 to 30%	> 40%
Energy saving	5 to 10%	20 to 30%	30 to 50%
Functions	Idle start/stop Regenerative braking Accessory powering	Start/stop idle Autonomous braking torque aid	Start/stop idle Electric traction and regenerative braking
Relative cost	Low	Medium	High
Example	Mercedes Smart And UFAA-19 Series Electric Vehicle	Honda Civic	Toyota Prius

Table 2-1: Comparison of different HEVs by the degree of hybridization

2.3.2 Classification according to layout of Powertrain system

A powertrain is a collection of parts in a car that transfers power from the engine to the wheels.. It regulates how much power is split between the internal combustion engine and the electric motor, which has an impact on the vehicle's cost, mechanical effectiveness, and fuel efficiency.

Hybrid electric vehicles are categorized into several categories based on the design of their powertrains.

- Series hybrid electric vehicle (SHEV)
- Parallel hybrid electric vehicles (PHEV)
- Series-parallel hybrid electric vehicles (SPHEV)
- Complex hybrid electric vehicles (CHEV)

2.3.2.1 SERIES HYBRID ELECTRIC VEHICLES

The electric motor in series hybrid vehicles provides traction power. Through an electric generator, a battery and a gasoline internal combustion engine work together to power the motor. The internal combustion engine is scaled back because its main purpose is to run the backup generator, which also charges the battery when it runs low on electricity. Power is distributed between the generator and the batteries under the control of a control system. These hybrid vehicles have the most straightforward drivetrain designs. The regenerative braking system is initiated when the vehicle brakes, and the motor acts as a generator to charge the batteries. Because they work best for start-and-stop drive cycles, series hybrids are ideal for usage in heavily trafficked urban areas. All of the motor power is provided by the batteries because internal combustion engines are not ideal in these circumstances. Due to the increased power requirements of the motor, series hybrid vehicles end up needing larger batteries. They cost more than parallel hybrids because of the bigger batteries, as well as the motor and generator.

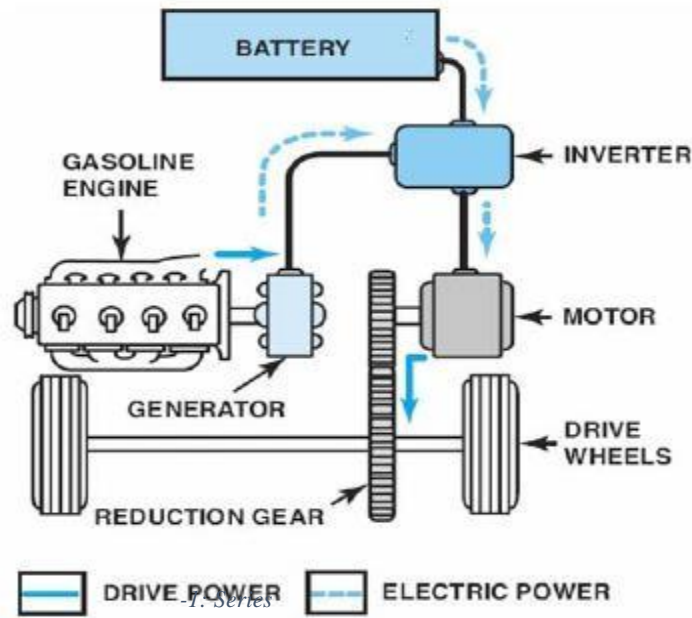


Figure 2-1: Series hybrid drivetrain structure

2.3.2.2 Parallel Hybrid Electric Vehicles

In a parallel hybrid vehicle, both the internal combustion engine and electric motor are connected to the wheels and work together to provide power and traction. They switch off using a clutch, with the motor also acting as an alternator as a result of regenerative braking to replenish the battery. They are more efficient on the highway, but require a larger engine and have higher inefficiencies and complexity in stop and go driving. Examples include the Honda Civic and UFAA-

19 SERIES HYBRID ELECTRIC VEHICLE

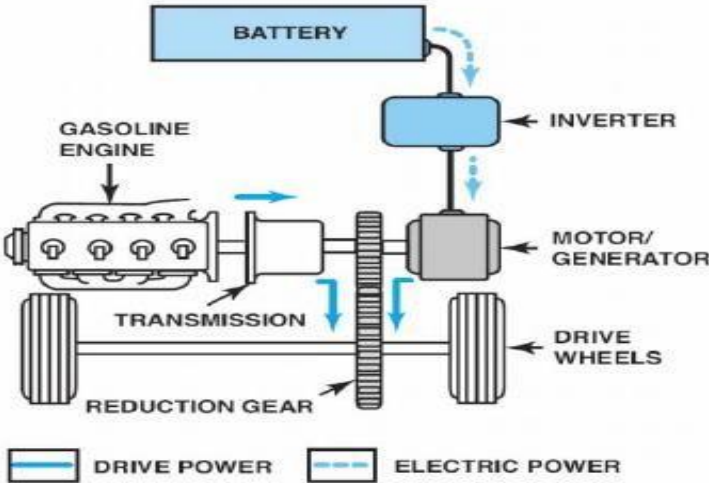


Figure 2-2: Parallel hybrid drivetrain structure

2.3.2.3 Series-Parallel Hybrid Electric Vehicles

Hybrids in series-parallel form, often known as combined hybrids, combine the benefits of both series and parallel hybrids. The internal combustion engine can either disconnect from the wheels to power the electric generator like a series hybrid, or provide power directly to the wheels like a parallel hybrid. At low speeds, they operate as a series hybrid, and at high speeds, as a parallel hybrid. They have more intricate drivetrain designs and smaller electric motors. The Toyota Prius is one example of a car with this kind of drivetrain.

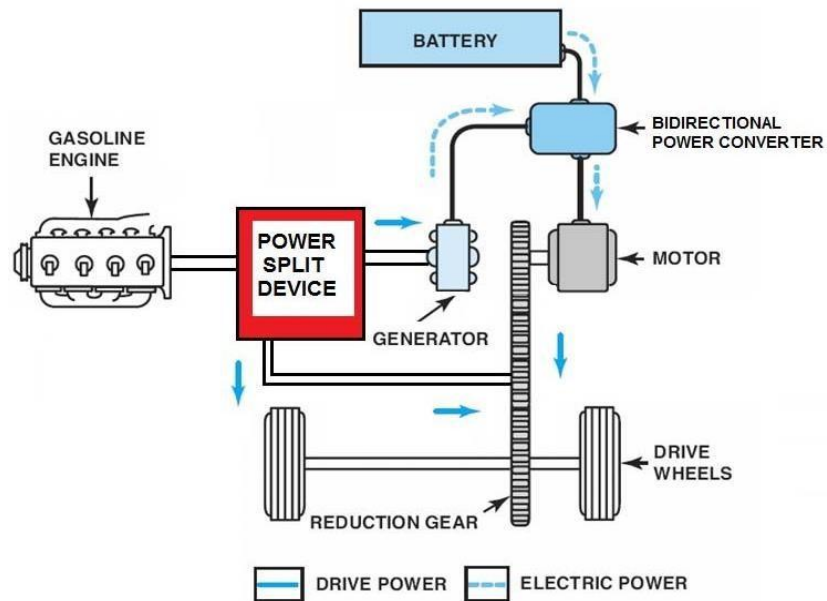


Figure 2-3: Series-parallel hybrid drivetrain structure

2.3.2.4 Complex Hybrid Electric Vehicles

In addition to switching between series and parallel configurations, complex hybrids are even more complicated than series-parallel hybrids since they also include a bidirectional power flow through the electric motor. They can have varying complexity depending on the number of motors/generators used in their design. Because of the extensive drivetrain, they are also highly expensive. The Ford Escape is a good illustration of a car using this kind of drivetrain.

2.3.3 Classification according to type of energy source used

Hybrid vehicles can be categorized according to the type of energy source they use into:

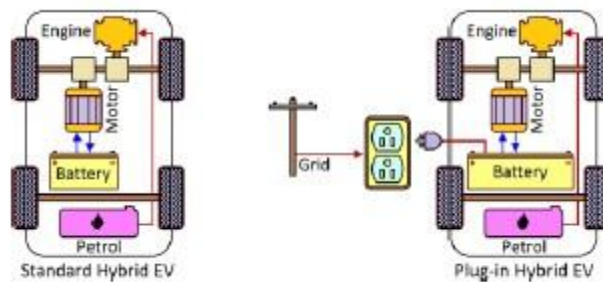
- Conventional hybrid electric vehicles
- Plugin hybrid electric vehicles (PHEV)

2.3.3.1 Conventional Hybrid Electric Vehicles

Conventional" hybrid vehicles combine an internal combustion engine and an electric motor, and they exclusively rely on fuels like gasoline or diesel. These hybrid vehicles can charge their batteries by regenerative braking but cannot be recharged from the power grid.

2.3.3.2 Plug-in Hybrid Electric Vehicles

In addition to having an internal combustion engine and an electric motor, plug-in hybrids (PHEVs) also have a sizable rechargeable battery. The vehicle can travel further on electric power alone because to this battery's ability to be charged by the electric grid. The control system of the PHEV monitors the battery's state of charge and switches to using the internal combustion engine when the battery's charge is low. PHEVs provide a number of benefits over conventional cars, including the ability to travel farther on an electric charge and the availability of cleaner, quieter technologies. Chevy Volt and Toyota Prius are two examples of PHEVs. A portion of the kinetic energy of the wheel is also converted into energy that may be stored in the battery by the regenerative braking system while the vehicle is being stopped.



*Figure 2-4: Standard (Conventional)
and Plug-in hybrid vehicles*

2.4 Parts of a Hybrid Electric Vehicle

Hybrid electric vehicles, regardless of the type, consist of certain common components.

- Prime mover
- Electric motor
- Controller
- Inverter
- Brake system
- Electric storage system (ESS)
- Transmission system

2.4.1 Prime Movers

Prime movers are machinery that transforms mechanical energy from natural sources of power. Turbines, internal combustion engines, and windmills are a few examples of prime movers. In the case of hybrid electric vehicles, internal combustion engines (using gasoline or diesel) or fuel cells are frequently utilized as the primary propulsion system.

A type of engine known as an internal combustion engine burns fuel inside of a small area known as a combustion chamber. When a fuel and an oxidizer interact exothermically, high-temperature, high-pressure gases are produced. These gases are then allowed to expand. The distinguishing characteristic of an internal combustion engine is that beneficial work is accomplished by the hot gases expanding and acting directly to generate movement, such as by acting on pistons,

rotors, or even by pressing and moving the entire engine. Internal combustion engines (ICEs) are a general name for devices that utilise intermittent combustion, such as reciprocating engines and Wankel engines. However, internal combustion engines also include continuous combustion devices such as jet engines, the majority of rockets, and many gas turbines. As opposed to using compression, the original internal combustion engines relied on an air-fuel mixture that could be sucked or blown in during the initial portion of the intake stroke. The use of compression, especially in-cylinder compression, distinguishes modern internal combustion engines from the earliest models in a significant way.

Applications

Internal combustion engines are commonly utilized for mobile applications, such as in automobiles, equipment, and portable machinery, due to their ability to provide high power-to-weight ratios and excellent fuel energy density. These engines are found in a wide range of vehicles such as cars, motorcycles, boats, and aircraft, as well as in locomotives. In situations where very high power is needed, such as in jet aircraft, helicopters, and large ships, internal combustion engines often take the form of turbines. Additionally, they are also used in electric generators and in various industrial settings.

OPERATION

All internal combustion engines rely on the exothermic chemical process of combustion, which involves the reaction of a fuel, typically with air, but other oxidizers such as nitrous oxide can also be used. The most common fuel used today is made up of hydrocarbons and is derived mostly from petroleum. These include diesel fuel, gasoline, and petroleum gas, and in rare cases propane gas can

be used. Most internal combustion engines designed to run on gasoline can also run on natural gas or liquified petroleum gases without major modifications, except for the fuel delivery components. Additionally, liquid and gaseous biofuels such as ethanol and biodiesel (a form of diesel fuel produced from crops that yield triglycerides such as soybean oil) can also be used. Some engines can also run on hydrogen gas. To create combustion, all internal combustion engines require a method for achieving ignition in their cylinders. Engines use either an electrical method or a compression ignition system.

GASOLINE IGNITION PROCESS

Electric/gasoline ignition systems use a lead-acid battery and induction coil to create a spark that ignites the fuel mixture in the engine's cylinders. The battery can be recharged while the engine is running using an alternator or generator. Gasoline engines mix air and gasoline, compress it, and use a spark plug to ignite the mixture when the piston is at the top of its compression stroke.

DIESEL ENGINE IGNITION PROCESS

Compression ignition systems, such as diesel and HCCI engines, use heat and pressure generated during the compression process for ignition. Compression in these engines is typically higher than in gasoline engines. In diesel engines, air is taken in and a small amount of diesel fuel is injected into the cylinder just before peak compression, causing the fuel to ignite instantly. HCCI engines also take in both air and fuel, but rely on unaided auto-combustion due to high pressure and heat. These engines may have difficulty starting in cold temperatures, but once running, they perform well. Diesel engines may also have battery and charging systems, but these systems are secondary and primarily used for starting,

controlling fuel, and running auxiliary components. Modern diesel engines often incorporate electronic systems to improve efficiency and reduce emissions.

ENERGY

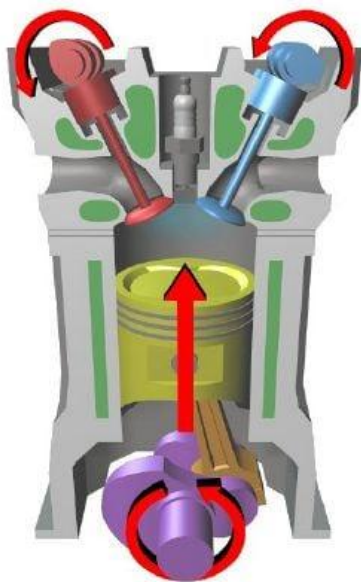
After ignition and combustion, the hot gases produced by the burning fuel/air mixture have more available energy than the original mixture. The engine can transform this energy, which is in the form of high pressure and temperature, into work. Gases under high pressure move the pistons of a reciprocating engine. A valve is opened or the exhaust outlet is exposed to expel the hot gases that are still present after the available energy has been taken, allowing the piston to return to its starting position. The piston then proceeds to the next phase of its cycle, which varies depending on the engine. Any heat not converted into work is typically considered waste and is removed from the engine through an air or liquid cooling system.

Components

Depending on the type of engine, different parts go into an engine. Important components in a four-stroke engine include the crankshaft, camshafts, and valves. A two-stroke engine, on the other hand, might just have a fuel input and an exhaust outlet. Both kinds of engines have one or more cylinders, with a spark plug, a piston, and a crank in each cylinder. The downward motion that follows the ignition of the fuel mixture is referred to as the power stroke. A single movement of the piston within the cylinder is referred to as a stroke. A Wankel engine has a triangular rotor that orbits in a figure-eight shaped chamber around an eccentric

shaft. Its four phases of operation (intake, compression, power, exhaust) take place in different locations, rather than one location like in a reciprocating engine.

A Bourke engine employs a pair of pistons connected to a Scotch Yoke that converts reciprocating motion into rotary motion through a specially designed bearing assembly. This yoke allows the intake, compression, power, and exhaust to occur during each stroke.



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Fig 2-5: An illustration of several key components in a typical four-stroke engine.

CLASSIFICATION

Internal combustion engines have a wide range of applications and as such, they come in a variety of types. There are also multiple ways to classify these engines, some of which include:

Principle of operation

Reciprocating:

- Crude oil engine
- Two-stroke cycle
- Four-stroke cycle
- Hot bulb engine
- Poppet valves
- Improvements
- Sleeve valve
- Atkinson cycle
- Controlled Combustion Engine

Rotary:

- Bourke engine
- Improvements
- Controlled Combustion Engine

Rotary:

- Demonstrated:
- Wankel engine
- Proposed:
- Orbital engine
- Quasiturbine
- Rotary Atkinson cycle engine

- Toroidal engine

Continuous combustion:

- Gas turbine
- Jet engine
- Rocket engine

Engine cycle

Two-stroke

Engines that operate on the two-stroke cycle use two strokes (one upward and one downward) for every power stroke. Since there are no dedicated intake or exhaust strokes, other methods are used to evacuate the cylinders. The most common method in spark-ignition two-stroke engines is to use the downward motion of the piston to pressurize fresh charge in the crankcase, which is then forced through the cylinder through ports in the cylinder walls. These engines are small and lightweight for their power output and are mechanically simple. In lawnmowers, chainsaws, weed eaters, jet skis, mopeds, outboard motors, and some motorbikes, they are frequently employed. They do not scale well to greater capacities and are typically noisier, less effective, and more polluting than four-stroke engines. The biggest two-stroke compression-ignition engines are seen in some locomotives and huge ships. These engines scavenge the cylinders via forced induction. Because unspent fuel might occasionally escape out of the exhaust duct with the previously spent fuel, two-stroke engines are less fuel-efficient than other types of engines. Without special exhaust processing, this can also produce high pollution levels, which is why many small engine applications such as lawnmowers use four-stroke

engines and smaller two-stroke engines are equipped with catalytic converters in some jurisdictions.

Four-stroke

Cars, bigger boats, and some light aircraft frequently use engines that run on the four-stroke cycle, also known as the Otto cycle. These engines have one power stroke for every four strokes (upward, downward, upward, downward). Typically, they are larger, more powerful, and quieter than their two-stroke cousins. These cycles come in a variety of forms, such as the Atkinson and Miller cycles. The majority of truck and automobile diesel engines employ a four-stroke cycle as well, but this variant is known as the diesel cycle because it uses a compression heating ignition mechanism.

Five-stroke

A version of the four-stroke cycle is the five-stroke cycle, which is used in engines. An engine typically goes through four cycles: intake, compression, combustion, and exhaust. Delautour included the refrigeration cycle as the fifth cycle. The efficiency of five-stroke engines can be up to 30% higher than that of comparable four-stroke engines.

Bourke engine

In this type of engine, two cylinders that are opposite each other are connected to the crankshaft through a common Scottish yoke. The cylinders and pistons are designed in such a way that, like in a typical two-stroke engine, there are two power strokes per revolution. The operation is cleaner and more effective because, unlike a conventional two-stroke engine, the burnt gases and the entering fresh air

do not mix in the cylinders. Additionally having little side thrust, the Scottish yoke mechanism significantly lessens friction between the pistons and cylinder walls. Compared to either four-stroke or two-stroke cycles, the combustion phase of the Bourke engine is closer to constant volume combustion. Additionally, it has fewer moving parts than the other two reciprocating types, which results in less friction. Additionally, compared to either four-stroke or two-stroke cycles, its higher expansion ratio means that more heat from the combustion phase is used.

Controlled combustion engine

The reciprocating motion of these cylinder-based engines, which can be single or two-stroke, is changed into rotary motion by two gear-connected, counter-rotating concentric cams rather than a crankshaft and piston rods. These cams significantly increase mechanical efficiency by effectively canceling out the sideward forces that the pistons would otherwise apply to the cylinders. The piston travel in relation to the torque produced is determined by the shape of the cam lobes, which are invariably odd-numbered and at least three in number. For each pair of counter-rotating cams in this engine, there are two cylinders that are 180 degrees apart. There are two times as many cycles per cylinder pair in two-stroke models as there are lobes on each cam in single-stroke ones.

Wankel

Given that the phases take place in various parts of the engine, the Wankel engine functions with the same separation of phases as a four-stroke engine (although as there are no piston strokes, it would actually be more appropriately referred to as a four-phase engine). This engine has a greater average power-to-weight ratio than

piston engines thanks to its three power "strokes" every rotor revolution. The Mazda RX8 and older RX7 models as well as other cars employ this type of engine.

Gas turbine

In contrast to piston-based cycles, gas turbine cycles, such as those found in jet engines, use separate compressors and gas turbines to compress and expand the gases. Continuous power is produced as a result. Compression and fuel combustion raise the temperature and volume of the intake gas, which is typically air. The compressor is subsequently powered by the gas turbine, which processes the combustion chamber's hotter, greater volume of gas.

Disused methods

In some early non-compressing internal combustion engines, a fuel-air mixture was sucked in during the initial downstroke of the piston. The inlet valve closed during the remaining portion of the piston's downstroke, igniting the fuel-air combination. The exhaust valve was open during the piston's upward motion. This design was an effort to emulate the operation of a piston steam engine.

Fuel and oxidizer types

Fuels that are commonly used to power engines include gasoline, liquified petroleum gas, compressed natural gas, hydrogen, diesel, jet fuel, landfill gas, biodiesel, bioethanol, and others. Gas engines are referred to as such, while oil engines are ones that run on liquid hydrocarbons; however, gasoline engines are frequently mislabeled as "gas engines." The basic restrictions on the fuels that can be utilized are that they must easily pass through the fuel system to the combustion

chamber and release enough heat energy during combustion to make the engine workable.

Air is frequently utilized as the oxidizer since it doesn't need to be stored inside the vehicle, which improves the power-to-weight ratio. However, air can also be compressed and transported inside of a vehicle, and certain submarines are made to do so by carrying hydrogen peroxide or pure oxygen. Nitrous oxide is used as an oxidizer in some race cars. Although some other compounds, such as fluorine or chlorine, have been used experimentally, most are not practicable.

At slower speeds, diesel engines are often heavier, louder, and more powerful than gasoline engines. They are employed in heavy road vehicles, some cars, ships, railroad locomotives, and light airplanes and are generally more fuel-efficient. The majority of other road vehicles, including most cars, motorbikes, and mopeds, are powered by gasoline. Be aware that since the 1990s, sophisticated diesel-engined automobiles have been fairly popular in Europe, accounting for about 40% of the market. Engines powered by gasoline or diesel both emit a lot of pollutants. Additionally, there are engines that run on biodiesel, hydrogen, methanol, ethanol, and other fuels. There are no longer any paraffin or tractor vaporizing oil (TVO) engines in use.

Hydrogen

There is conjecture that as hydrogen fuel cell technology advances, existing fuels such as gasoline and oil may one day be rendered obsolete. Contrary to fossil fuels, which also produce other pollutants like carbon monoxide, sulfur dioxide, and nitrogen oxides that can cause respiratory problems, acid rain, and ozone problems, hydrogen combustion only produces water. Carbon dioxide, a major cause of

global warming, is a product of fossil fuel combustion. However, producing hydrogen is currently not a cost-effective method and needs a substantial amount of energy. Additionally, because to its low density and requirement for large tankage, hydrogen is challenging to store and transport. Even when liquefied, hydrogen's volumetric energetic storage is still around five times smaller than that of gasoline, while having a greater specific energy. Biofuels, which emit no net carbon dioxide, are another environmentally benign substitute for conventional fuels.

Cylinders

One to twelve cylinders are the most frequent numbers for internal combustion engines, while as many as 36 have been employed. An engine with more cylinders may have two advantages: first, it may have a higher displacement with fewer individual reciprocating masses, resulting in an engine that runs more smoothly. Second, an engine may produce more torque if it has a larger displacement and more pistons because more fuel can be burned and there can be more combustion events in a given amount of time. The drawback of having more pistons is that it tends to weigh more and produce more internal friction, which reduces fuel efficiency and saps some of the power from the engine. Although there are outliers like the W16 engine from Volkswagen, there seems to be a break point for high performance gasoline engines utilizing current materials and technology around 10 or 12 cylinders after which adding more cylinders becomes detrimental to performance and efficiency.

- Some very small automobiles and trucks only have two or three cylinders, whereas some high-performance vehicles have 10, twelve, or even sixteen. 4 to 8 cylinders are the usual number for car engines. The DKW and Saab 92

were two-cylinder, two-stroke engines that were once seen in certain relatively big automobiles.

- The Pratt & Whitney R-4360 was one of the last radial aviation engines, which are now considered outdated. A row has an odd number of cylinders; hence a two- or four-row engine is indicated by an even number. With 36 cylinders (four rows of nine cylinders), the Lycoming R-7755 was the largest of them but it was never put into production.
- The typical number of cylinders in motorcycles is one to four, with a few high-performance versions having six (though some "novelties" exist with 8, 10, and 12).
- Snowmobiles typically have two cylinders. Some larger vehicles, including those utilized for touring as well as high performance, have four.
- Chainsaws, generators, and home lawn mowers are examples of small, portable appliances that typically feature one cylinder, however two-cylinder chainsaws are also available.

Ignition system

The ignition system of internal combustion engines, which controls when the fuel/oxidizer mixture ignites, is used to classify these engines. This impacts the effectiveness and output of the engine. When the crankshaft reaches 90 degrees after TDC in a conventional 4-stroke car engine, the mixture should ignite at the point of maximum pressure. The pace of the flame front is influenced by variables including compression ratio, fuel mixture temperature, and gasoline octane or cetane grade. In order to avoid the flame front striking the descending piston, which can result in banging or pinking, modern ignition systems work to ignite the mixture at the ideal timing. Advanced ignition timing is needed for engines with

leaner mixtures and lower mixture pressures. While other systems, like flame and hot-tube systems, have been used in the past, the majority of engines today use electrical or compression heating systems for ignition. In 1898, Nikola Tesla received one of the earliest patents for a mechanical ignition system.

Fuel system

When a big surface area of a fuel comes into touch with oxygen, it burns more effectively. Engines require a fuel-air mixture (sometimes known as a fuel-air vapor mixture) to operate effectively. Carburetors and fuel injection are the two most used ways to vaporize fuel into air. In straightforward reciprocating engines, carburetors are employed, but they do not offer exact control over the amount of gasoline given to the engine. They continue to be utilized in small engine applications like lawnmowers and were commonly employed in automobiles before the mid-1980s. Fuel injection systems are used in larger gasoline and diesel engines. Engines for autogas (LPG) either use open-loop or closed-loop carburetors, or both. In addition to using burners, other internal combustion engines like jet engines and rocket engines also employ a variety of techniques such as impinging jets, gas/liquid shear, preburners, and a host of other concepts.

Engine configuration

The configuration of internal combustion engines can be used to categorize them, which has an impact on their size and smoothness. Common configurations include V-shaped, flat or boxer, and straight or inline. For greater cooling, aircraft engines may also feature a radial arrangement. There have also been instances of less common configurations like "H," "U," "X," or "W.". A cylinder head is not necessary in multiple-crankshaft arrangements, which instead use opposed piston

designs, which place a piston at each end of the cylinder. The Junkers Jumo 205 and Napier Deltic diesel engines, as well as current maritime engines for propulsion and generators, were built using this concept. Early aircraft employed the Gnome Rotary engine, which included a stationary crankshaft and a bank of rotating cylinders positioned radially around it.

Engine capacity

An engine's displacement or volume swept by the pistons is referred to as its capacity. For bigger engines, it is normally measured in liters or cubic inches, and for smaller engines, in cubic centimeters. Larger engines often have higher power output and provide greater torque at lower RPMs, but they also use more gasoline. The stroke can be lengthened or the piston diameter can be raised to boost an engine's capacity. For the best performance, however, it could also be required to make changes to the fuel intake. Instead of engineering, marketing factors may have an impact on an engine's capacity. For instance, the BMC A-Series engine used in the Austin-Healey Sprite Mark II, Morris Minor 1000, and Morris 1100 all had the same stroke and bore but were advertised with different capacities (1000cc, 1100cc, and 1098cc, respectively) in the sales material.

Lubrication system

Engine lubricating systems come in a variety of varieties. Simple two-stroke engines lubricate by squirting oil into the induction stream or blending it with the gasoline. Early slow-speed stationary and marine engines employed tiny chambers akin to those used on steam engines for gravity-based lubrication. The requirement for a high power-to-weight ratio resulted in higher speeds, higher temperatures, and more pressure on bearings as engines were modified for use in automobiles

and aircraft. For the crank bearings and connecting rod journals, this requires pressure lubrication, which can be accomplished directly by a pump or indirectly by a jet of oil directed at pickup cups on the connecting rod ends. This has the benefit of increasing pressure as engine speed rises

Engine pollution

Due to incomplete fuel combustion, internal combustion engines—especially reciprocating ones—produce substantial levels of pollution, including unburned hydrocarbons, soot, oxides of nitrogen and sulfur, and carbon monoxide. For gasoline engines, the need to operate close to stoichiometry and the cooling effect of the cylinder walls on the combustion process are the main causes of this. Along with other types of pollution, diesel engines can release tiny particles that can get deep inside a person's lungs. In contrast, liquefied petroleum gas (LPG)-powered engines produce very little pollution because LPG burns cleanly and doesn't contain sulfur or lead.

- Many fuels contain sulfur, which can lead to the release of sulfur oxides (SO_x) in the exhaust, contributing to acid rain.
- The high temperature of combustion leads to increased production of nitrogen oxides (NO_x), which have been shown to be harmful to both plant and animal health.
- Engines do not necessarily produce net carbon dioxide, but most engines that run on fossil fuels do. However, if engines are powered by biomass, they do not produce net carbon dioxide as the plants used for the biomass absorb an equal or greater amount of carbon dioxide during growth.

- Nitrogen oxides will also be formed if air is utilized as the oxidizer instead of hydrogen in hydrogen engines, which only produce water as a byproduct.

INTERNAL COMBUSTION ENGINE EFFICIENCY

Internal combustion engine efficiency can vary greatly depending on the type, with gasoline-powered engines typically having a mechanical efficiency of around 20%. Energy is often wasted as heat lost to the cooling system and exhaust, with only a small percentage lost to friction. To increase fuel economy, add-on systems such as Hydrogen Fuel Injection (HFI) can be used, which can result in an increase in fuel economy of between 15% and 50%. Additionally, new types of internal combustion engines, such as the Scuderi Split Cycle Engine, which use high compression pressures and combust after top-dead-center, are expected to achieve efficiencies of 50-55%.

2.4.2 Electric Motor

By leveraging the interplay between the motor's magnetic field and an electric current in the wire winding, which results in torque on the shaft, an electric motor is a device that transforms electrical energy into mechanical energy. It can be powered by AC sources like power grids, inverters, or generators or by DC sources like batteries. Similar to gasoline generators, electric generators transform mechanical energy into electrical energy. Motors are built for continuous rotation or linear movement over a sizable distance. They produce linear or rotary force to

drive external mechanisms. Only a short distance can be covered by solenoids, which similarly transfer electrical power to mechanical motion.

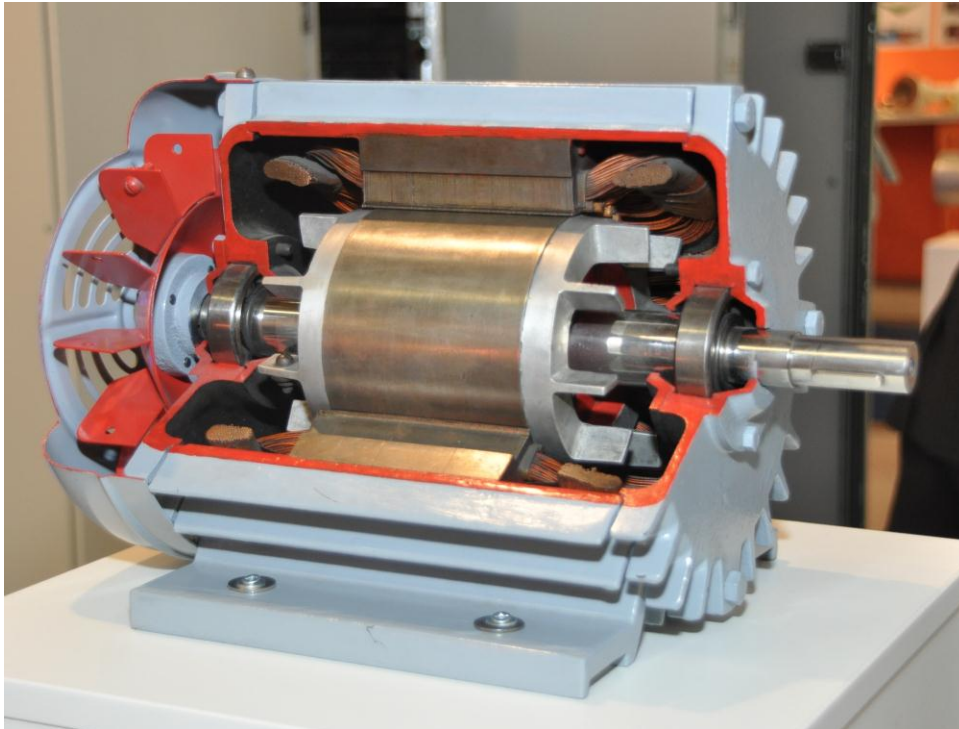


Fig 2-6: Electric motor

A motor is made up of two parts that interact with each other to create a magnetic circuit. These parts are electrically connected.

- **Field magnets** - A magnetic field is produced by this component and travels through the armature. The magnetic field is normally directed by a collection of

electromagnets arranged around the rotor and composed of wire coils on a ferromagnetic iron core. Another possibility is a permanent magnet or magnets.

- **Armature** - This part enables the flow of electric current, which produces force. It is constructed of wire windings on a ferromagnetic core, just like the field coils. The magnetic field of the field magnet exerts a force known as the Lorentz force on the wire when electrical current flows through it, rotating the rotor.

A motor consists of two primary parts, one of which is attached to the stator, the motor's stationary portion, and the other to the rotating portion (the rotor). Normal placement of the armature and field magnet on the stator and rotor, respectively, may be reversed in several motor types.

Rotor

In an electric motor, the rotor, which is the moving component, turns the shaft to provide mechanical power. Typically, the rotor has conductors that carry currents; these currents are influenced by the magnetic field of the stator and cause the rotor to rotate. Some rotors feature permanent magnets, and the stator supports the conductors. Permanent magnet rotors are effective throughout a broad range of operating speeds and power levels. The rotor cannot rotate unless there is a very little space between the stator and rotor. The motor's performance may be impacted by this gap, so it is often kept as narrow as possible to reduce any adverse consequences. Very small gaps, however, can also result in mechanical problems, noise, and losses.

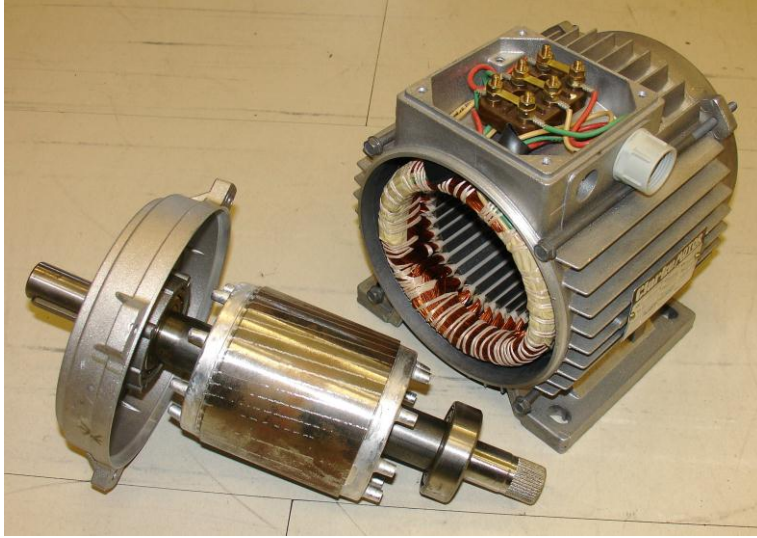


Fig 2-7: Electric motor rotor (left) and stator (right)

Stator

The stator, which surrounds the rotor and is the fixed element of the motor's electromagnetic circuit, often has field magnets, which can be either permanent magnets or electromagnets made of wire windings around ferromagnetic iron cores. In order to apply force on the windings, it produces a magnetic field that passes through the rotor armature. In order to reduce energy losses that would occur if a solid core were employed, the stator core is made of thin, thermally-insulated metal sheets, or laminations. Resin-encased motors, which are frequently used in air conditioners and washing machines, utilise the dampening qualities of resin to reduce noise and vibration. These motors completely encase the stator in plastic.

Bearing

The support offered by the motor housing allows the rotor, which rests on bearings, to rotate. The motor shaft travels through the bearings and connects to the load

outside of the motor. Because the forces the load generates are positioned outside of the outermost bearing, the load is regarded as overhung.

Windings

Electric machines' magnetic cores can be set up to create magnetic poles when powered by current. The two basic configuration types are salient-pole and nonsalient-pole. In a salient-pole machine, a wire is wound around each of the protruding poles on the ferromagnetic cores of the rotor and stator that face one another. The poles of a wire become the north or south poles of a magnetic field when current flows through it. The ferromagnetic core of a nonsalient-pole device is a smooth cylinder with equally spaced windings in slots around the circumference. Rotating poles are produced in the core by alternating current in the windings. A winding that wraps around a portion of the pole of a shaded-pole motor delays the magnetic field's phase. Some motors that run on electromagnetic induction employ thicker conductors like copper or aluminum bars. Electric machines use windings, which are coils of wire that are often wrapped around a core of laminated soft iron.

Commutator

A commutator is a part of some motors that feeds the rotor current by switching the direction of the current every half turn. It consists of "brushes" formed of conductive material that push on the commutator as it rotates and a cylinder of metal contact segments on the armature. Commutators are inefficient, though, and other motor types including brushless DC, permanent magnet, and induction motors have largely taken their places

2.4.2.1 Classification of Electric Motors

Based on the source of electrical power, two types of electric motors can be distinguished: AC and DC. They have several classifications and are employed in numerous applications.

- a) **AC Electric Motor:** An alternating electrical current is transformed into mechanical torque by AC electric motors. The need for and capabilities of AC electric motors have increased as a result of the increasing usage of AC power systems for power distribution. Both 2-phase and 3-phase AC systems, which produce a rotating magnetic field in the stator, can be used to power these motors. Different types of AC motors, such as induction (asynchronous) and synchronous motors, operate on the basis of this field.
 - a. **Induction Motor:** Induction motors are AC motors that produce armature current using electromagnetic induction. The rotor is subjected to torque and rotates at a slightly slower rate than the stator field thanks to the revolving magnetic field produced by the stator windings, which also produces an alternating current in the rotor windings. Based on the design of its rotor, induction motors can be categorized as either phase-wound or squirrel cage motors.
 - b. **Synchronous Motor:** Synchronous motors are AC motors that cannot start on their own and must be propelled into action by an outside source. A spinning magnetic field is produced by the multi-phase power supply, but because the field is alternating, the rotor's poles cannot entirely align with it. Due of its high inertia, this results in the rotor being pushed back and forth yet it does not revolve. To avoid this, the stator field is ignited before the motor has been externally

accelerated. It locks in place and the system rotates in unison once the rotor speed meets the field.

b) **DC Electric Motor:** Direct current (DC) motors are electric motors that use electricity to create mechanical motion. Based on how the current is switched, they can be divided into two types: brushed and brushless.

a. **Brushed DC Motor:** Internally commutated brushless DC motors use split rings and carbon brushes to regulate the flow of current to the rotor windings. Due to the broad adoption of DC power distribution systems, these were among the first motor types employed in commercial and industrial settings. The supplied voltage or applied load can be changed to change the speed of brushed DC motors. Another category for brushed DC motors is self-excited and separately excited types. While the stator and rotor windings of self-excited DC motors are both powered by the same DC sources, the field windings of separately excited DC motors are powered by a different DC source. Self-excited DC motors can also be further broken down into series, shunt, and compound motors based on the type of connection between the two windings.

b. **Brushless DC Motor:** Electronically commutated DC motors that perform similarly to induction motors are brushless DC motors, sometimes referred to as BLDC motors. The rotor is made up of permanent magnets, and they use electronic circuitry to provide a single or multi-phased trapezoidal or sinusoidal DC voltage to the stator windings. The rotor and the field produced by the stator both revolve at the same frequency, and sensors known as Hall Effect The

rotor's position is tracked by sensors, which help engineers choose which field windings to activate or deactivate.

The diagram below illustrates the different categorizations of electric motors:

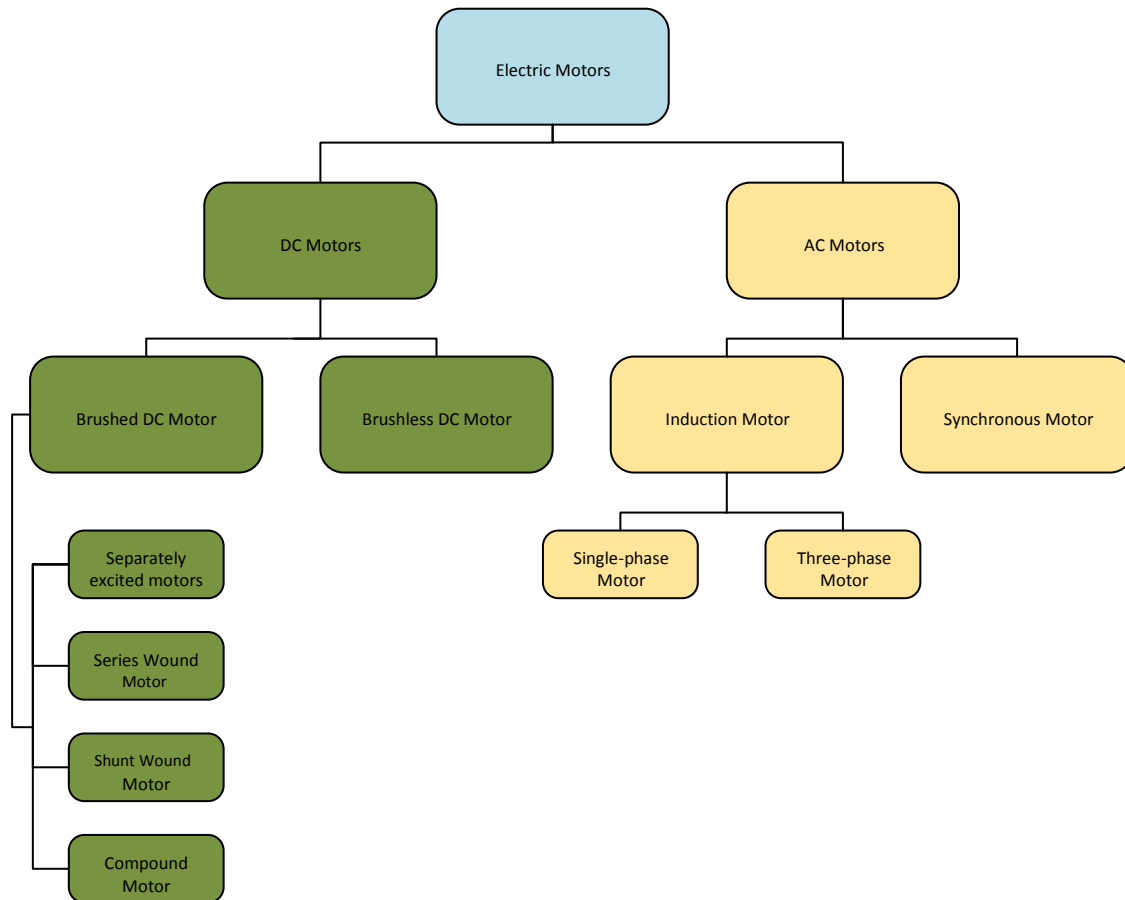


Figure 2-8: Classifications of electric motors

In electric and hybrid systems, especially those driven by batteries, DC motors are frequently employed. Due to its strong performance over a wide range of speeds

and relatively inexpensive cost, brushless DC (BLDC) motors have become more common in electric cars (Dimitrov and Koeva 2020).

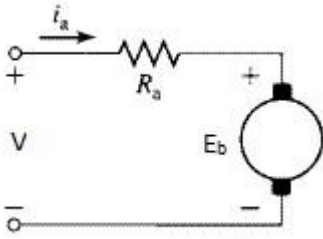


Figure 2-9: Equivalent circuit for a DC motor

The similar circuit for a DC motor running steadily is shown in the diagram above. The Kirchhoff's Voltage Law-described governing equation of the system would be significantly impacted by the inductance of the rotor windings during starting.

$$V = i_a R_a + E_b \quad 2.2$$

i_a = winding current

R_a = winding resistance

E_b = Back emf

The induced emf in the rotor windings (back emf), which is determined by Faraday's Law of Electromagnetic Induction, is equal to the flux change rate.

$$E_b = \frac{d\phi}{dt}$$

The flux rate is related to the motor parameters, flux (ϕ), number of armature windings (Z), armature parallel paths (Z), and poles (P), by the relation

$$\frac{d\phi}{dt} = \frac{ZN\phi}{60} \times \frac{P}{A}$$

$$\therefore E_b = \frac{ZN\phi}{60} \times \frac{P}{A}$$

The aforementioned relation can be simplified to

$$E_b = K_\omega \omega \quad 2.3$$

As previously stated, the energy expended to overcome the back emf is converted to mechanical torque.

$$T\omega = i_a E_b$$

$$T \times \frac{2\pi N}{60} = i_a \frac{ZN\phi}{60} \times \frac{P}{A}$$

$$T = \frac{1}{2\pi} Z\phi i_a \left(\frac{P}{A} \right)$$

Again, at constant flux (shunt motors)

$$T = K_t i_a \quad 2.4$$

We can see from equations 2.3 and 2.4 that the dc motor's torque and rotational speed are directly proportional to the current and back emf, respectively. We may obtain the steady state equation for the dc motor by substituting those two equations into the energy balance equation (equation 2.2).

$$T = \frac{K_t}{R_a} V - \frac{K_t K_\omega}{R_a} \omega \quad 2.5$$

The aforementioned equation depicts the speed-torque characteristic relation for a conventional DC motor, and it shows that when the voltage is constant, the speed of the motor will vary inversely with the torque

2.4.2.2 Brushless DC (BLDC) Motors

The recommended option for electric and hybrid systems is a brushless DC (BLDC) motor, as was already indicated.

BLDC motors have the following benefits over other types of DC motors:

- Long-lasting.
- Improved acceleration and torque capabilities.
- A high ratio of torque to weight.
- Silent or Quiet operation.
- Wide range of velocities
- Improved performance.

While BLDC motors with a rated voltage of 100V or greater are typically employed in industrial automation applications, those with a voltage of 48V or less are frequently used in the automotive and robotics industries (Yedamale, 2003). The stator, rotor, and Hall Effect sensor are the basic parts of a BLDC motor.

2.4.2.2.3 Hall Sensor

As was already noted, BLDC motors are electrically commutated, which means that data from a Hall Effect sensor is used to maintain their spin. This sensor determines the rotor's location in relation to the stator using Edwin Hall's 1879 discovery of the Hall Effect hypothesis as its foundation. The controller uses this information to determine which winding should be set to high or low. Three Hall Effect sensors are often mounted to the stator of BLDC motors.

2.4.3 Motor Controller

A DC motor controller is a piece of equipment that regulates a DC motor's torque, speed, and position. It allows for starting and stopping the motor, controlling its direction of rotation, adjusting its speed and torque, and safeguarding against

overloading. It can be operated manually, automatically, or remotely. It could also come with extra characteristics.

2.4.3.1 BLDC Motor Controller

The input from the Hall Effect sensors determines the commutation sequence, as was already described. The control circuit energizes one winding, de-energizes the other, and leaves the third winding neutral as the rotor moves close to a sensor. The interaction between the two fields created generates torque, which declines as the rotor tries to line up with the field of the stator. By alternating between energized and de-excited windings, the stator fields are adjusted to maintain torque. The term "Six-Step Commutation (Trapezoidal Control)" refers to this process. As a result, the controller generates a 3-phase DC signal that the BLDC motor uses as a commutation signal. The controller modifies its output voltage to regulate the motor's speed.

2.4.4 Energy Storage System

Vehicle energy storage systems come in a variety of configurations. The conventional internal combustion engine runs on fossil fuels, however although having a high energy density, these fuels are linked to escalating environmental problems. Battery technology has become a feasible alternative because it doesn't emit toxic gases. Although batteries now have a lower energy density than fossil fuels, research is being done to increase this. In the parts that follow, we'll enlarge on the subject of batteries.

2.4.4.1 The Battery

A battery is a type of electrical appliance that uses the redox reaction to transform chemical energy into electrical energy. They come in various forms and sizes, from

powering small devices to providing energy for homes. They can be simple, single-use batteries or advanced rechargeable batteries, and are used in many fields and industries. Batteries are a cleaner alternative to fossil fuels for powering vehicles. To recharge a battery, an electrical current is applied in the opposite direction of the discharge process, reversing the chemical reactions and allowing the positive ions to return to the anode, making it ready for use again.

The main constraint of battery technology for EVs is the battery technology itself. The first generation of EVs faced limitations in battery technology, which include:

- large weight
- limited range
- poor endurance
- lengthy charging period

Much progress has been made in battery technology since then, but there is still room for improvement. In the following sections, we will explore the current battery technologies available, their limitations and the compromises being made to overcome them, and potential advancements that will be crucial for the widespread adoption of EVs.

EV batteries are distinct from those used in smaller electronics, they need to provide large amounts of power over a prolonged period while also being compact, lightweight, and affordable.

More formally, these characteristics are:

- Specific energy is a measure of the energy a battery can hold per kilogram.
- Energy density, or how much energy is contained in a given amount of space

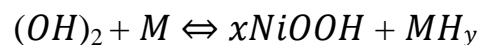
- The maximum amount of power that a battery can deliver is its power density.

Current battery research is focused on improving the parameters such as energy density, power density, and cost, as the energy density of gasoline far exceeds that of current batteries.

The two battery types that are most frequently employed in the EV sector are the more seasoned Nickel Metal Hydride (NiMH) and the more recent and optimistic Lithium-ion batteries (Li-ion).

2.4.4.1.1 NiMH Battery

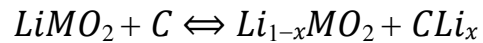
NiMH batteries have an anode made of rare-earth or nickel alloys and a cathode composed of potassium hydroxides. They are particularly suitable for EVs as they are cost-effective, have high power and energy density, and are environmentally friendly. The chemical reaction for these batteries is:



2.4.4.1.2 Li-ion Battery

Graphite serves as the negative electrode in Li-ion batteries, which normally include a positive electrode built of a lithium compound. Because of their high energy and power density, they are preferred for usage in EVs and are frequently used in portable gadgets and medical equipment. Additionally, they weigh less than NiMH batteries. Their capacity, energy density, cycle life, and performance

are currently being studied. The main issues with Li-ion batteries, however, are their high discharge current, the requirement for a protection circuit, and their high price. These batteries' chemical reaction is as follows:



2.5 Go-Kart

Small, four-wheeled recreational vehicles generally known as go-karts are frequently used for racing (karting). Hugh Cameron, a Scottish artist, first used the word "Go-Cart" in 1885 in his work "The Go-Cart" (Art UK, n.d.). After the war, airmen invented go-karts as a means of recreation. American Art Ingnels, known as the "father of karting," constructed the first racing kart in history in Southern California in 1956. (Nilawar et al. 2016). The first company to produce go-karts was an American one called Go-Kart Manufacturing Co. With the release of the MC10 in 1959, McCulloch became the first business to make go-kart engines (Vintage Karts 2002).

Go-karts have become incredibly popular over time. Nowadays, karting is viewed as a stepping stone to professional racing.

2.6 Parts of a Go-Kart

A typical go-kart includes five parts:

- Chassis
- Steering system
- Power system
- Drivetrain
- Braking system

2.6.1 Chassis

Moly chrome tubing is usually used in the construction of the go-kart chassis or frame (Fédération Internationale de l'Automobile, 2005). Go-karts lack suspension, so their chassis is made to be very flexible in order to absorb shocks. Different categories of go-kart chassis are typically used to group them.

- An open chassis go-kart is one that does not have a cage enclosing the vehicle.
- A caged chassis go-kart is one that has a cage that surrounds the vehicle.
- A straight chassis go-kart is one where the driver sits in the center of the vehicle.
- An offset chassis go-kart is one where the driver sits on the left side of the vehicle

2.6.2 Steering

The steering mechanism, which is an essential part of a vehicle, allows for smooth and efficient changes in direction. It utilizes mechanical linkages or gears to rotate the front wheels. The assembly of these components converts the rotation of the steering column into the rotation of the front wheels. A high-quality steering system should possess certain characteristics, including:

1. The accuracy of the driver's inputs should be reflected in the response of the steering system.
2. It should be designed with a functional mechanism that allows the wheels to return to their original position when there is no input from the driver.
3. The vehicle should be easy to steer with minimal effort required from the driver.

4. It should be simple to operate and should provide precise results.

According to Pramanik in 2002, the Ackermann steering system is the norm for four-wheeled vehicles. In order to deal with the issue of different turning radii between the two front tires, it makes use of a set of mechanical linkages. Through this design, the wheels are kept from sliding when making turns. This steering system's most important feature is that the wheels' axles should make concentric circles as they travel along a curved path. The center of these circles should be situated along the axis of the rear axle because the rear wheels are fixed.

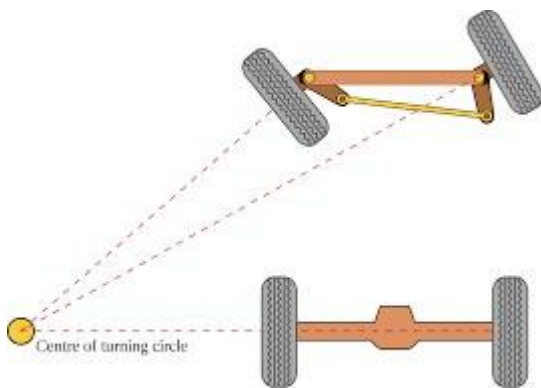


Figure 2-10: Ackermann steering geometry

Consider a car with four wheels rotating around. Its center of rotation has the following radius R.

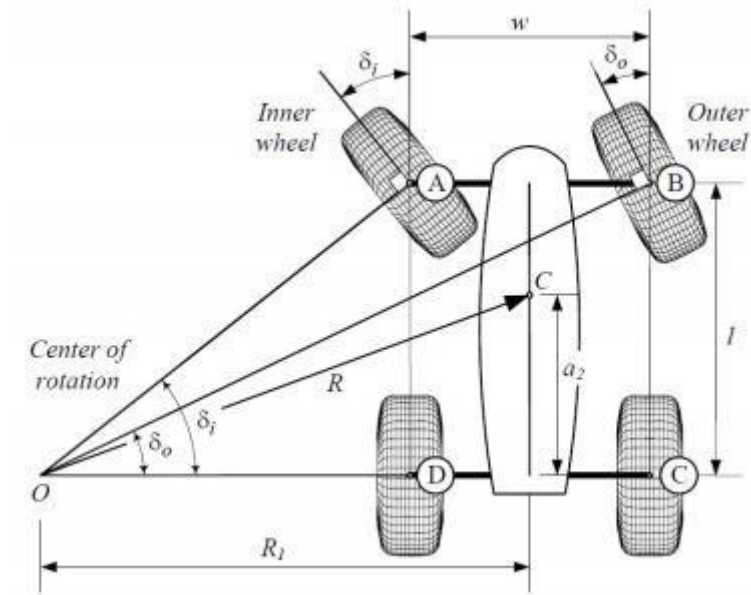


Figure 2-11: Diagram labelling the action of a four-wheeler making a turn

δ_i = inner wheel's steering angle

δ_o = The outer wheel's steering angle

l = wheelbase (distance between the axles of the front and rear tyres) w = track (distance along the axle of the steerable wheel)

From $\triangle OAD$ and $\triangle OBC$,

$$\tan \delta_i = \frac{l}{R_1 - w}$$

$$\tan \delta_o = \frac{l}{R_1 + w}$$

Eliminating R_1 and combining the two equations,

$$\frac{w}{l} = \cot \delta_o - \cot \delta_i$$

The necessary requirement that an Ackermann steering must meet is described by the aforementioned equation. Similar research demonstrates that the vehicle's radius of rotation is provided by (Benyeogor and Kumar 2020).

$$\text{Radius, } R = \sqrt{a_2 - l^2(\cot \delta)^2} \quad 2.6$$

2.6.3 Power System

Go-karts, similar to other vehicles, have various options for propulsion systems to generate the force needed to move them. These can include electric motors or internal combustion engines. The power output of these systems is typically lower than that of traditional vehicles due to the lightweight and compact design of go-karts.

2.6.4 Drivetrain

The typical drive system for go-karts is rear-wheel drive, as this is a common configuration for racing vehicles.

2.6.5 Braking System

The braking system in automobiles slows the vehicle down by applying friction, and this same principle is used in go-karts. Go-karts can use either disk brakes or brake drums as the braking mechanism, but disk brakes are more effective for rear-wheeled vehicles like go-karts. According to Ambashta et al. (2017), disk brakes

provide more reliable and efficient stopping power, dissipate heat more quickly, and are more convenient to use than brake drums.

2.7 Vehicle Dynamics

The illustration below illustrates the forces acting on a vehicle as it accelerates uphill. The diagram depicts the vehicle moving at a velocity of V , on an incline, and against wind velocity V_w . The vehicle's net force is determined by its mass and acceleration, in accordance with Newton's Second Law of Motion.

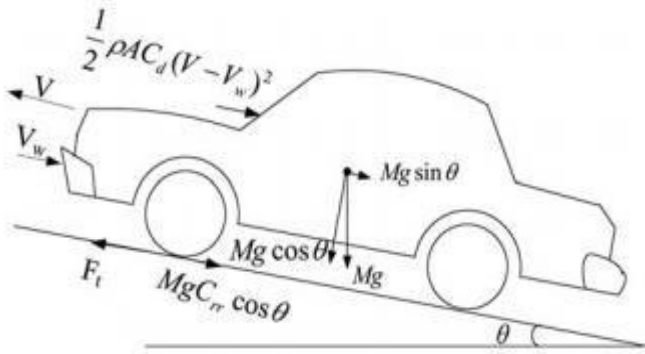


Figure 2-12: Free body diagram of a vehicle accelerating up an inclination

$$F_t - \sum F_r = f_m M \alpha$$

Where F_t = Traction force acting on the vehicle

$\sum F_r$ = Sum of all the resisting forces (drag, frictional and component of the vehicle's weight in its direction motion)

M = Overall mass of the vehicle

α = Acceleration of the vehicle

f_m = mass factor for converting the rotational mass of the rotating components into translating mass

$$\begin{aligned} \sum F_r &= F_D + F_f + Mg \sin \theta \\ &= \frac{1}{2} \rho A C_d (V - V_w)^2 + Mg C_{rr} \cos \theta + Mg \sin \theta \end{aligned}$$

Where A = Frontal area of the vehicle
 ρ = Density of air

C_d = Drag coefficient

C_{rr} = Coefficient of rolling resistance

The total propulsion force is then given by

$$\Rightarrow \text{Traction force, } F_t = f_m M \alpha + \frac{1}{2} \rho A C_d (V - V_w)^2 + Mg C_{rr} \cos \theta + Mg \sin \theta$$

The amount of force needed to propel the car at a given speed, V , is provided by the.

$$\text{Power, } P = F_r \times V = f_m M \alpha V + \frac{1}{2} \rho A C_d V (V - V_w)^2 + Mg V C_{rr} \cos \theta + Mg V \sin \theta$$

2.8 Review of Related Literature

In order to study the performance characteristics of their two-wheeled hybrid electric system, Balasubramani N. and colleagues designed, built, and tested the system. They used an IC engine to power the vehicle's back and an electric motor hub to power the front. They put the system through testing in three different modes—engine, electric, and hybrid—and compared the outcomes to those of a typical two-wheeler system. When the IC engine was utilized to maintain cruising speed and the electric motor was employed to generate high torque at start-up, they discovered that the system provided twice the mileage of a typical vehicle. Additionally, they discovered that the hybrid system produced 50% less pollutants (Balasubramani et al. 2018).

For the 2009 Shell Eco-marathon competition, Grundit E. and team used MATLAB/Simulink software to model and simulate the series hybrid vehicle Smarter. They changed the drivetrain's parts and looked at how it affected fuel economy. They discovered that the car, Smarter, would travel 255 kilometers per

liter of fuel and finish in tenth place in the competition, despite never having the model validated with a real model. They also found that further modifying the drivetrain characteristics did not significantly alter the vehicle's fuel efficiency, and they recommended researching the parallel hybrid system (Grunditz and Jansson 2009).

A modular Advanced Vehicle Simulator was used by Chuddy and colleagues to do research on the effectiveness of a parallel and series hybrid system (ADVISOR). In order to evaluate the savings from parallel and series systems with the fuel efficiency of the two IC systems operating separately, research was done on these systems. In comparison to the IC engine operating alone and the series hybrid system, the fuel efficiency was determined to be 24% and 4% better, respectively (Tammi, Minav, and Kortelainen 2018).

A study on the impact of hybridization on a vehicle's fuel efficiency and dynamic performance was presented by Lukic and his team. They looked at three distinct hybrid classifications for a typical passenger car (micro, mild, and full). Their research demonstrated that low-hybridization factor automobiles can offer a reasonable level of fuel economy at a low cost. They also discovered that the ideal level of hybridization depends on the power needs of the vehicle and ranges from 30 to 50%. (Lukic and Emadi 2004).

The fuel savings from a hybrid electric vehicle were the subject of research by Kwasi-effah and team. Based on the Toyota Prius series hybrid car, they built a MATLAB/Simulink model of the hybrid system. They looked at the model's fuel use when it was given data from the Highway Fuel Economy Test (HWFET) and the Urban Dynamometer Driving Schedule (UDDS). With emissions of 75g/km for CO₂, 0.096g/km for HC, 1.362g/km for CO, and 0.066g/km for NO_x, they

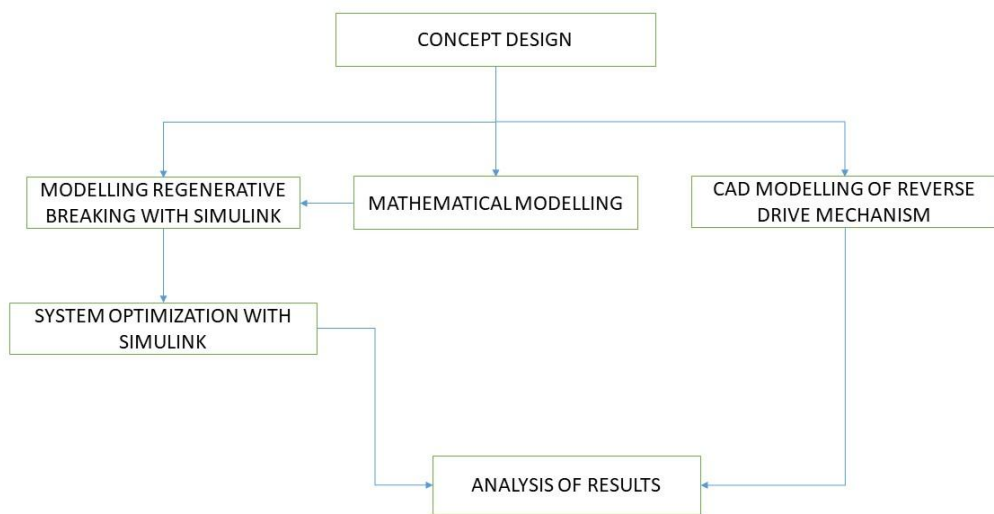
discovered that the series-parallel system reduced vehicular emissions by nearly 60%. (Kwasi-effah and Obanor 2013).

Kwasi-Effah et al. carried out the design and fabrication of the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE. They tested it in the department of mechanical engineering of the University of Benin. They discovered that a regenerative braking system and a suitable body design was needed to give the vehicle better performance (kwasi-Effah,Igbeka,Ataman, Emenime and Eguakun 2020).

CHAPTER 3

3.0 METHODOLOGY

In designing an optimum regenerative braking system for the UFAA-19 SERIES HYBRID ELECTRIC VEHICLE and the design of a suitable (aesthetic) body work, a flow chart outlining the entire design process is shown in fig 3.1 below. It guides the processes involved in meeting the performance requirements of low carbon emission and fuel-efficient drive train technology which is required for better performance.



3.1
Design
Flow
Chart

Fig 3-1: The Design Flow Chart

Fig 3.1

3.2 Concept Design

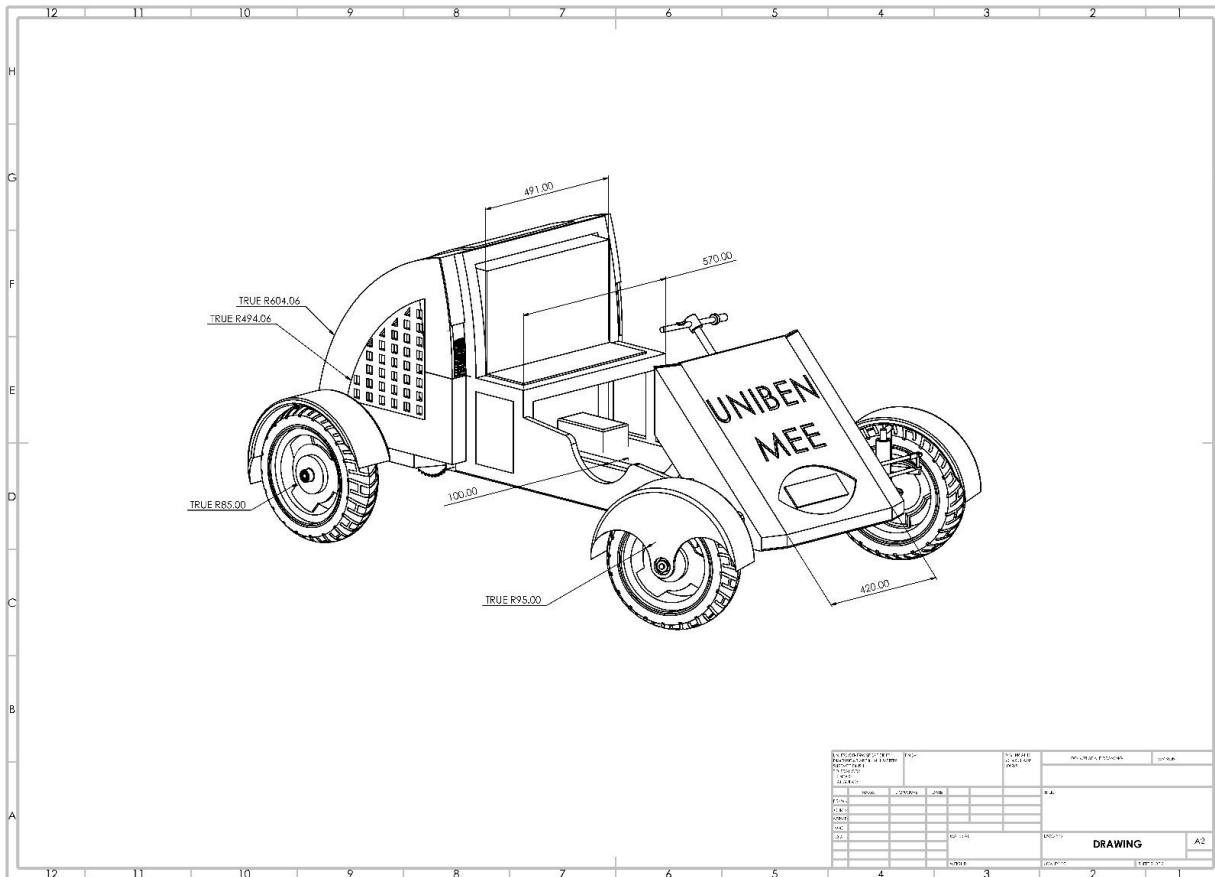


Fig 3-2: The Conceptual Design

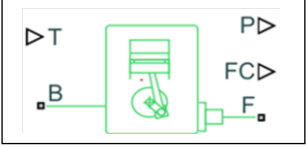
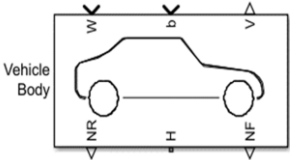
Model	EK50 (50cc)
Type	2 stroke, one cylinder, air-cooled
Bore*Stroke	40*38mm
Compression ratio	16:1
Ignition	CDI
Spark plug	Z4C 14mm
Displacement	50cc
Power	1.6Kw
RPM	6000rpm
Gas	≥90# Octane
Fuel Consumption	1.5L/100Km
Gas and Oil mixture	16:1
Maximum Speed	30km/h



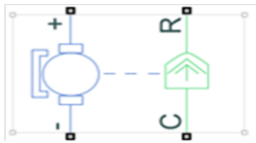
Specifications of the Electric Motor

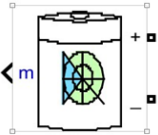
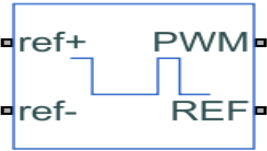

Model	BM1418ZXF(BLDC)
Motor Size	240*175*145mm
Motor type	Brushless DC Motor

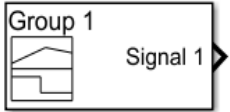
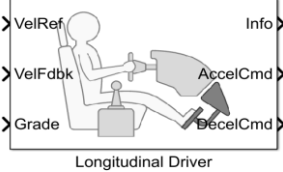
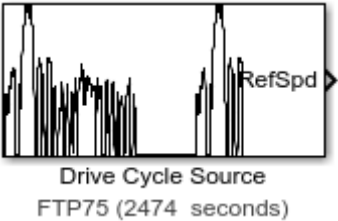
Rated Voltage	48V
Phase Angle	120°
Rated Power	0.75kw
No load Current	5.0A
No load Speed	3100rpm
Rated Speed	2800Rpm
Rated Current	21A
Rated Torque	2.56Nm
Efficiency	80%
Maximum Load	400kg
Reduction Ratio	6:1
Actual Speed	450rpm
Motor Gear	14 teeth
Driving Speed	~25km/h

The aim is to demonstrate the concept of regenerative braking and how it affects the state of charge of the battery and fuel consumption rate. In other to generate the model, the following blocks were used to represent the system component.

Block Name	Simulink Representation	Description
Generic Engine		<p>The block represents a general internal combustion engine. Engine types include spark ignition and diesel. Speed-power, P, and speed-torque, F, parameterizations are provided. A throttle physical signal input, T, specifies the normalized engine torque. Optional dynamic parameters include crankshaft inertia and response time lag. A physical signal port outputs the engine fuel consumption rate based on the choice of fuel consumption model</p>
Vehicle Body		<p>This block models the body of go-cart in terms of longitudinal dynamics, parallel to the ground and oriented along the direction of motion. The block accounts for body mass, aerodynamic drag, road incline, and weight distribution between axles due to acceleration and road profile.</p>

<p>Tire</p>	 <p>The diagram shows a cross-section of a tire mounted on a wheel hub. Four ports are labeled: 'S' on the left, 'A' at the bottom, 'H' on the right, and 'N' at the top. Each port has a small square or triangle symbol indicating its function.</p>	<p>This block models the tires of the vehicle. Connection A is the mechanical rotational conserving port for the wheel axle. Connection H is the mechanical translational conserving port for the wheel hub through which the thrust developed by the tire is applied to the vehicle. Connection N is a physical signal input port that applies the normal force acting on the tire. The force is considered positive if it acts downwards. Connection S is a physical signal output port that reports the tire slip.</p>
<p>Chain Drive</p>	 <p>The diagram shows a green rectangular block representing a chain drive. Inside, two sprockets are connected by a roller chain. The sprockets are labeled 'A' on the left and 'B' on the right. The chain is shown with green links and sprockets.</p>	<p>This block represents a power transmission system. with a chain and two sprockets connected by a roller chain. Connections A and B are the mechanical rotational conserving ports associated with sprocket A and sprocket B, respectively.</p>
<p>Electric Motor</p>	 <p>The diagram shows a blue rectangular block representing an electric motor. On the left, there are two electrical ports labeled '+' (positive) and '-' (negative). On the right, there are two mechanical ports labeled 'R' (rotational) and 'C' (conserving). A dashed line connects the motor symbol to the mechanical ports.</p>	<p>This block represents the electrical and torque characteristics of a DC motor. When a positive current flows from the electrical + to - ports, a positive torque acts from the mechanical C to R ports.</p>

<p>Battery</p>		<p>The Battery block implements a generic dynamic model, parameterized (in terms of the actual battery capacity in Ah and voltage) to represent a lead acid type of rechargeable battery.</p>
<p>Controlled PWM Voltage</p>		<p>This block creates a Pulse-Width Modulated (PWM) voltage across the PWM and REF ports. The output voltage is zero when the pulse is low and is equal to the Output voltage amplitude parameter when high.</p>
<p>H-Bridge</p>		<p>This block represents an H-bridge motor drive. The block is driven by the Controlled PWM Voltage block in the Averaged mode, which applies an average voltage to the load to achieve the correct average load current. <i>With the help of this block, regenerative braking is simulated.</i></p>

<p>Signer Builder</p>		<p>The Signal Builder block allows you to create interchangeable groups of piecewise linear signal sources and use them in a model.</p>
<p>Longitudinal driver (PI controller)</p>		<p>The Longitudinal Driver block implements a longitudinal speed-tracking PI controller. Based on reference and feedback velocities, the block generates normalized acceleration and braking commands ranging from 0 to 1. Hence the block models the dynamic response of a driver, which generates the commands necessary to track a longitudinal drive cycle.</p>
<p>Drive Cycle</p>		<p>A longitudinal drive cycle can be generated using the Drive Cycle Source block according to user or industry standards. The provided vehicle longitudinal speed is the block output. The drive cycle used by this model is the FTP75 cycle.</p>

3.3.1 Design Specification of the System

Parameters	Specification
Battery Capacity and Voltage	18Ah, 48volt
Maximum total weight of the Vehicle assembly	150kg

Assumptions Made During the Simulation

1. Electric and mechanical power losses were neglected
2. Viscous damping in the chains was neglected
3. wheels never lose contact with the ground
4. Acceleration due to gravity = $9.81m/s^2$
5. Wind speed is the same as the linear speed of the vehicle

3.3.2 Simulation for Regenerative Braking When Vehicle is on the Electric Mode

Regenerative braking is an electrical means of braking, in which the kinetic energy released during deceleration is transferred via a generator, and stored in the battery storage system thereby improving the state of charge of the battery. To demonstrate this, the model shown below was developed.

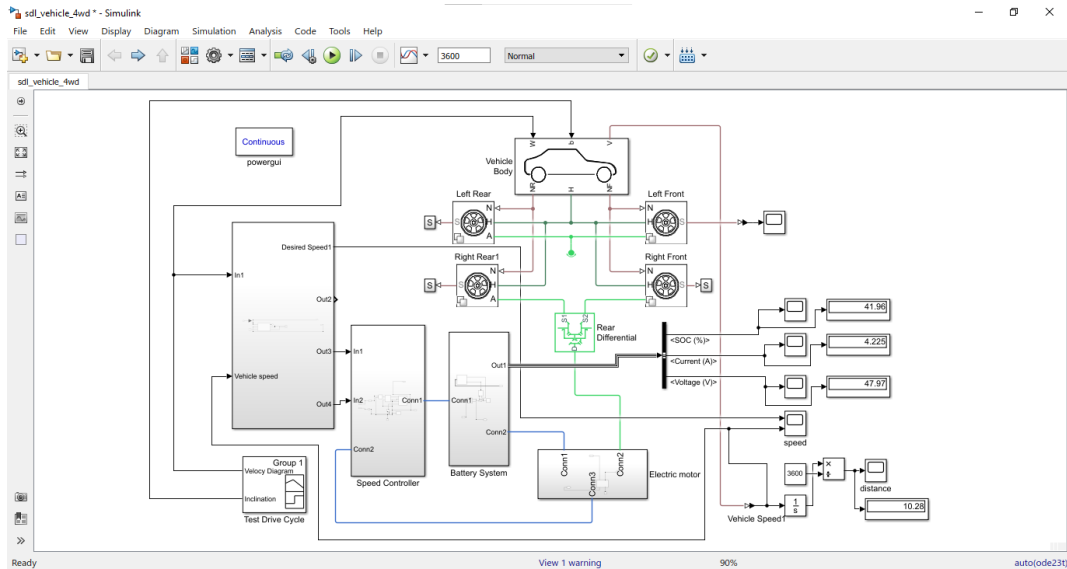


Fig. 3-4:

3.3.3 Operation of Electric Mode Simulation

In the simulation, the hybrid vehicle is powered solely by an electric DC motor. During the deceleration phase of the drive cycle, regenerative braking is utilized. The drive cycle inputs velocity-time values to the longitudinal driver, which sends either brake or acceleration signals to the drivetrain and includes factors such as wind speed and terrain incline. The output signal from the longitudinal driver is converted to a Pulse-Width Modulated voltage signal and sent to the H-Bridge, which then sends it to the battery for adjustments in voltage, current, and state of charge. The battery then supplies power to the DC Motor in the drivetrain, which applies torque to the rear shaft of the vehicle through the drivetrain. The vehicle's velocity is measured and sent back to the longitudinal driver, creating a closed-loop control system.

The Motor Parameters adjusted to that of the actual Dc motor as shown below

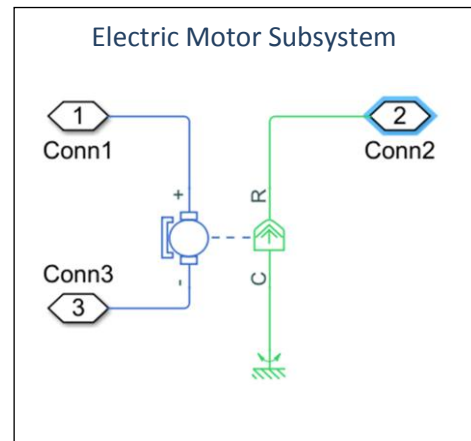
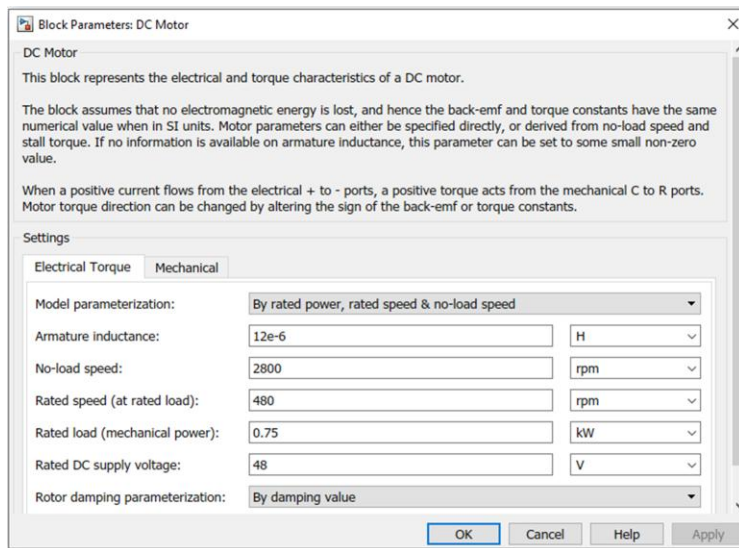


Fig 3-5

Battery Parameters set to the actual battery as shown

Battery Subsystem

Block Parameters: Battery

Battery (mask) (link)
 Implements a generic battery model for most popular battery types. Temperature and aging (due to cycling) effects can be specified for Lithium-Ion battery type.

Parameters **Discharge**

Type: **Lead-Acid**

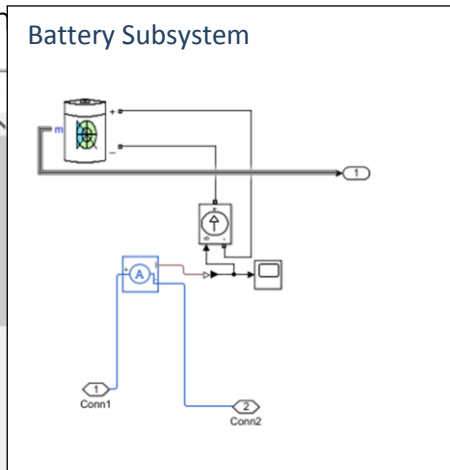
Nominal voltage (V): **48**

Rated capacity (Ah): **18**

Initial state-of-charge (%): **100**

Battery response time (s): **30**

OK Cancel Help Apply



Battery Discharge Characteristic Curve

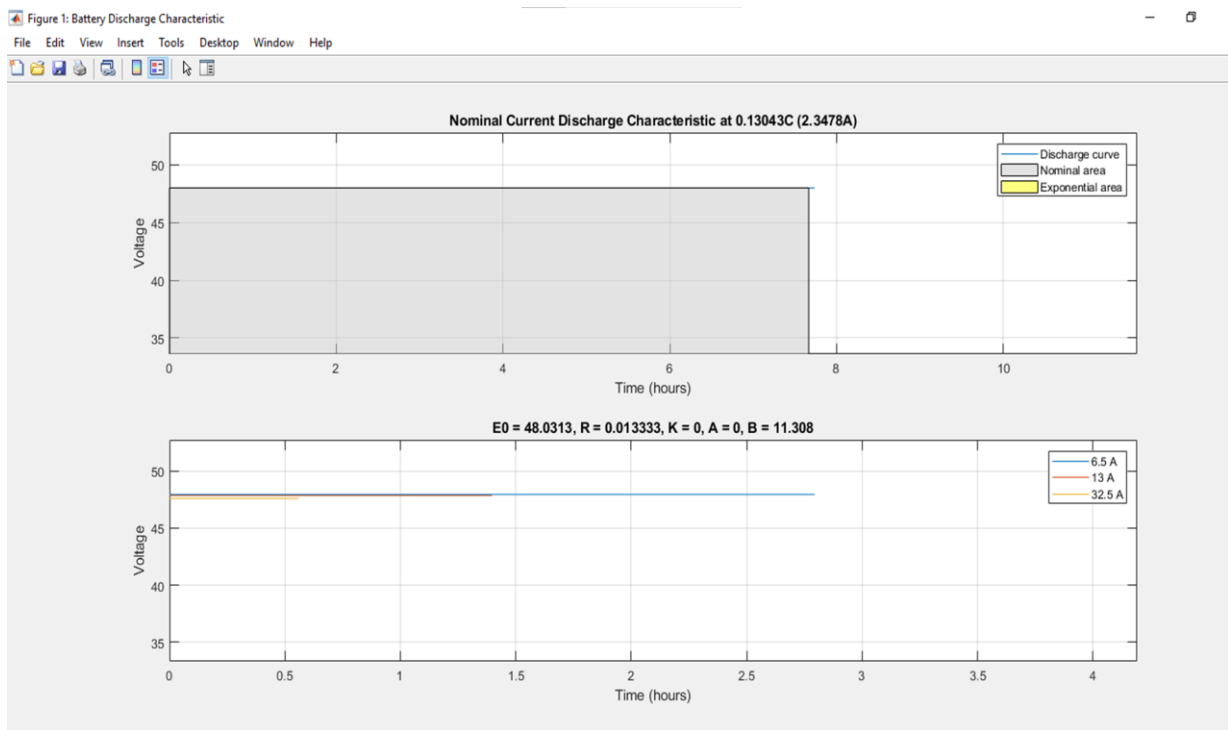


Fig 3-6:

The vehicle body Parameter were set as shown below

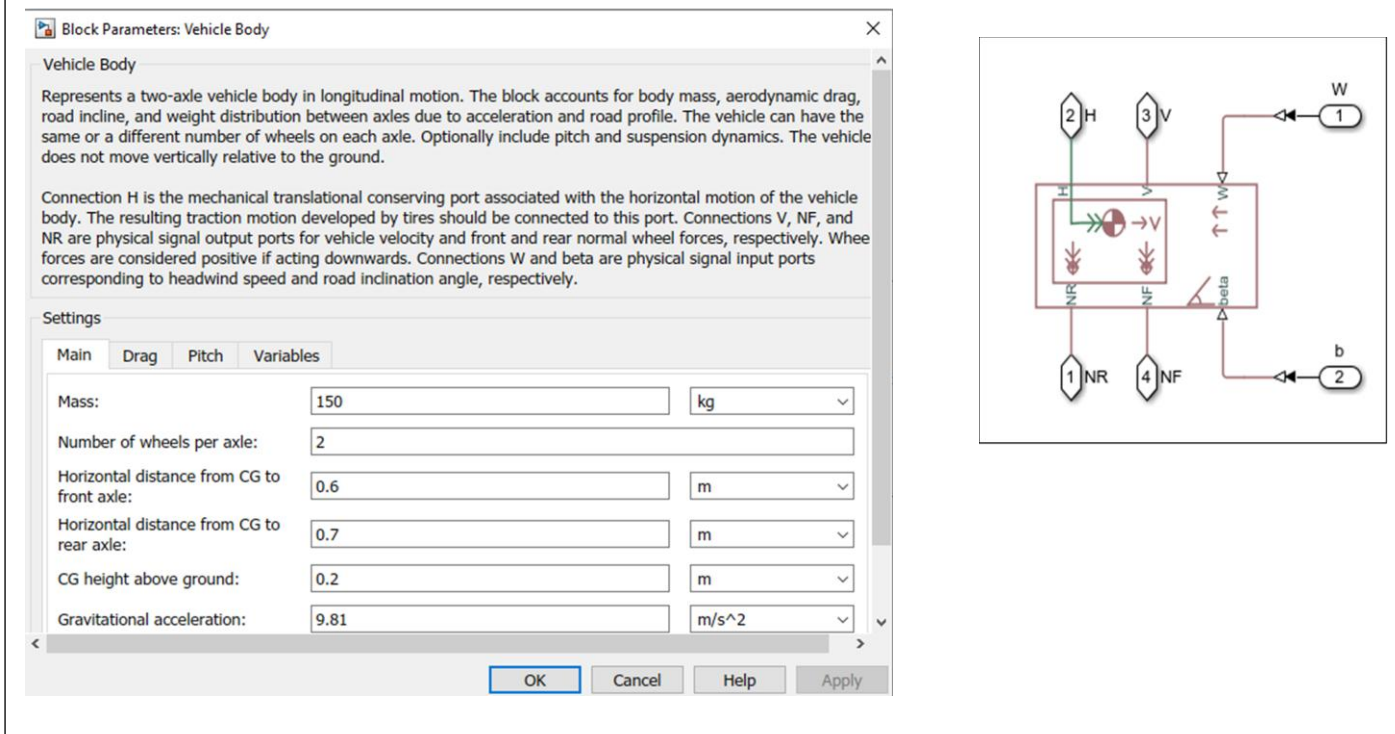


Fig 3-7:

3.3.5 The Drive Cycle

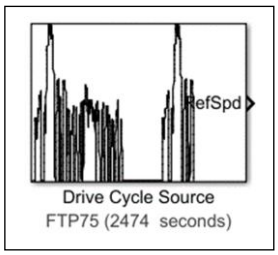
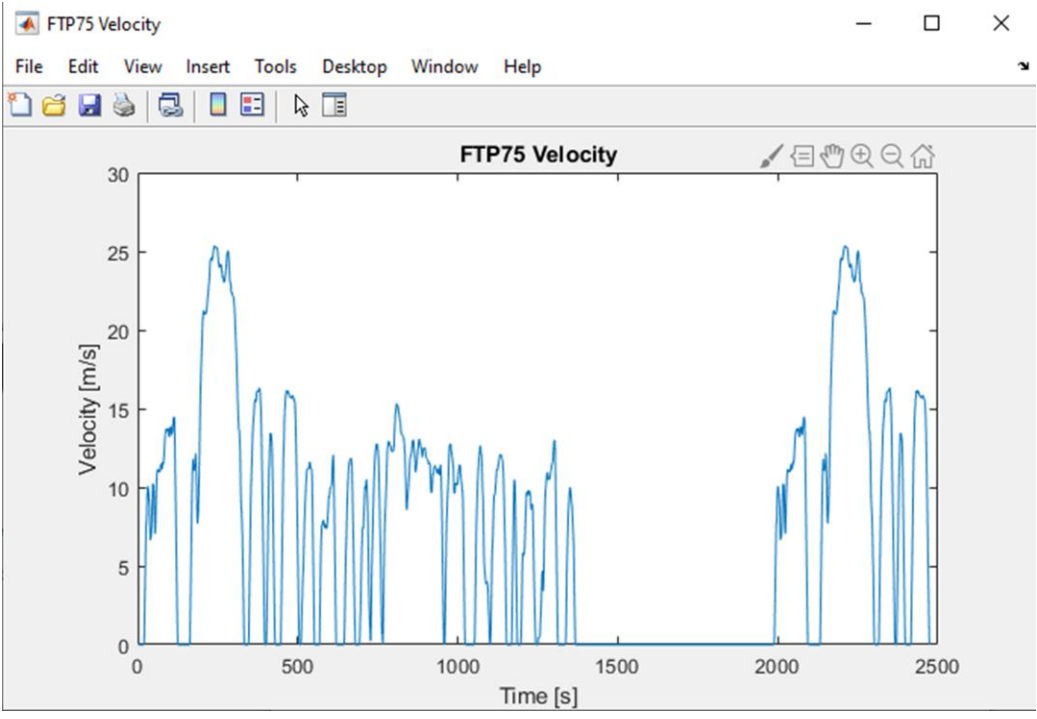
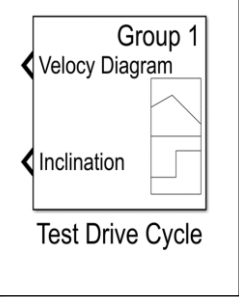
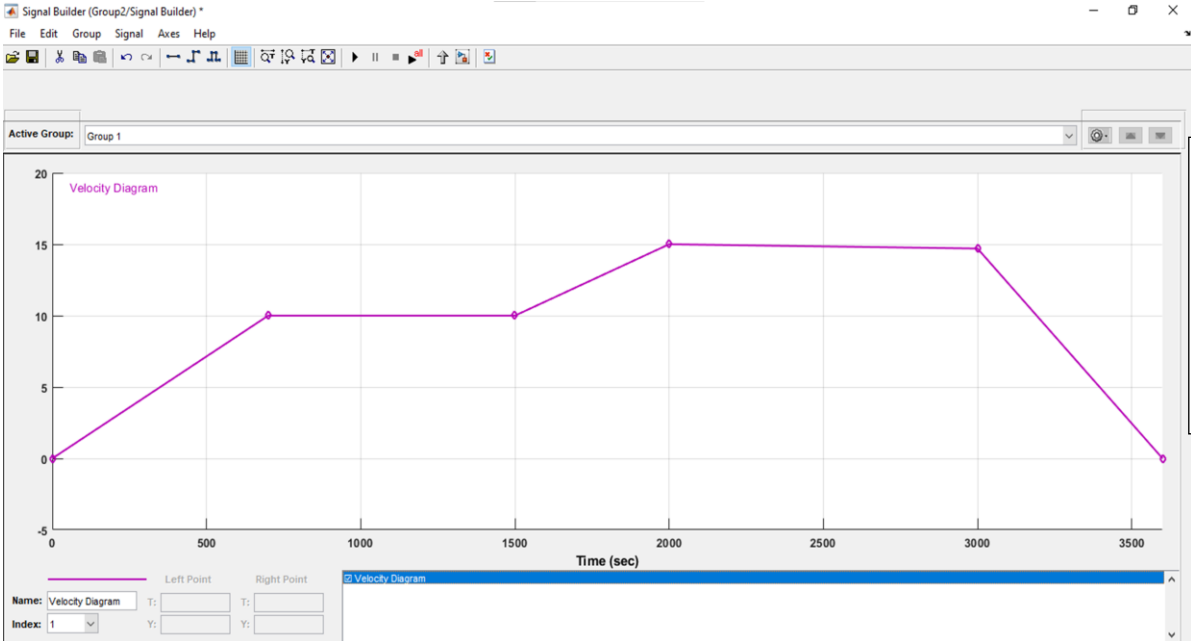
Drive cycles are used to simulate the performance of propulsion systems, such as internal combustion engines, electric drive systems, and batteries. They can be based on theoretical calculations or actual measurements of representative driving patterns.

There are two types of driving cycles:

- Transient driving cycles involve many changes, representing the constant speed changes typical of on-road driving. The FTP75 drive cycle is used for this purpose.
- Modal driving cycles involve protracted periods at constant speeds. The signal builder block will be used for this purpose

Modal Drive Cycle

In order to simulate for regenerative braking the velocity diagram use to describe the longitudinal motion of the vehicle is shown below



The aim of this simulation is to demonstrate the changes in the battery state of charge as the engine speed varies according to the input throttle signal. The Simulink model used for this simulation is shown below.

Transient Drive Cycle

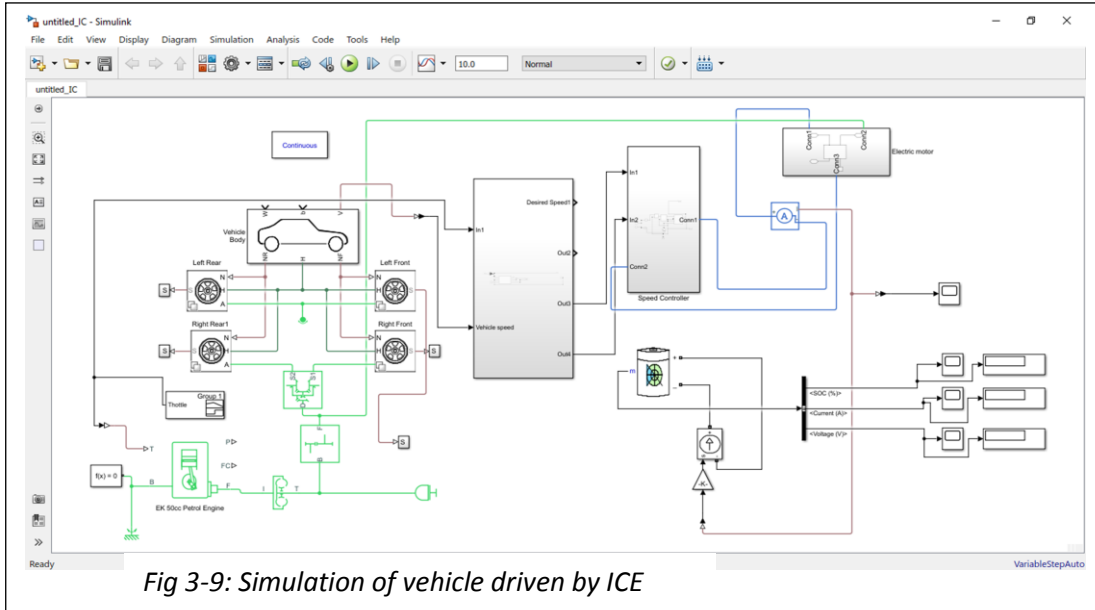
Fig 3-8:

3.3.6 THE STATE OF CHARGE OF BATTERY (SOC)

An electric battery's charge level relative to its capacity is defined as its state of charge, SOC. The SOC is measured as a percentage point of its relative capacity (where 0%=empty;100%=full). The depth of charge (DoD) is another form of the same measure; it is the inverse of SOC, in which 0%=full;100%=empty. When discussing the current state of the battery, the SOC is usually used, while the DoD is most often seen when discussing the lifetime of the battery after repeated use (i.e. its life cycle). The SOC of an electric vehicle's battery pack is the fuel gauge's equivalence (Auto / Keemut 2020). Direct measurement of the SOC is usually difficult, but it can be estimated from the direct measurement of battery variables. One such method is the Voltage method. This method uses the known discharge curve (voltage Vs SoC) of the battery to convert the reading of battery voltage to SOC (mpoweruk n.d.). Most rechargeable batteries are not meant to be fully discharged. In fact, fully discharging some batteries can permanently damage them. Hence there is a limit of discharge for which battery life is optimised. The battery minimum state of charge is the discharge limit in which the storage bank is cut off from supplying electric dc current. It is specified as a percentage of the total capacity. The minimum state of charge is typically set to (30-50)% in order to avoid damaging the storage bank by excessive discharge (HOMER ENERGY n.d.)

3.3.7 Simulation for Regenerative braking when Vehicle is Driven by

Internal Combustion Engine

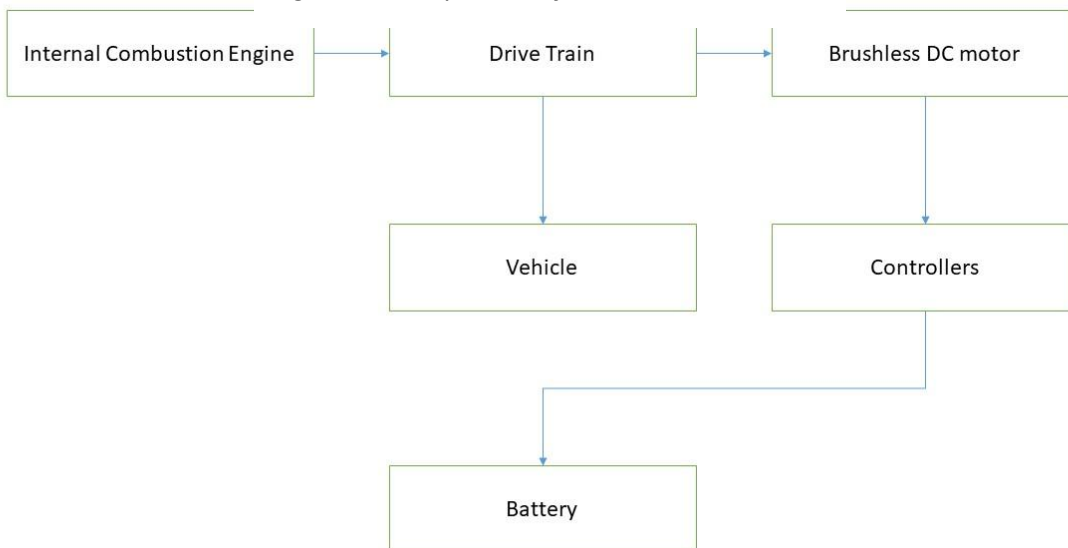


3.3.8 Operation of IC Mode Simulation

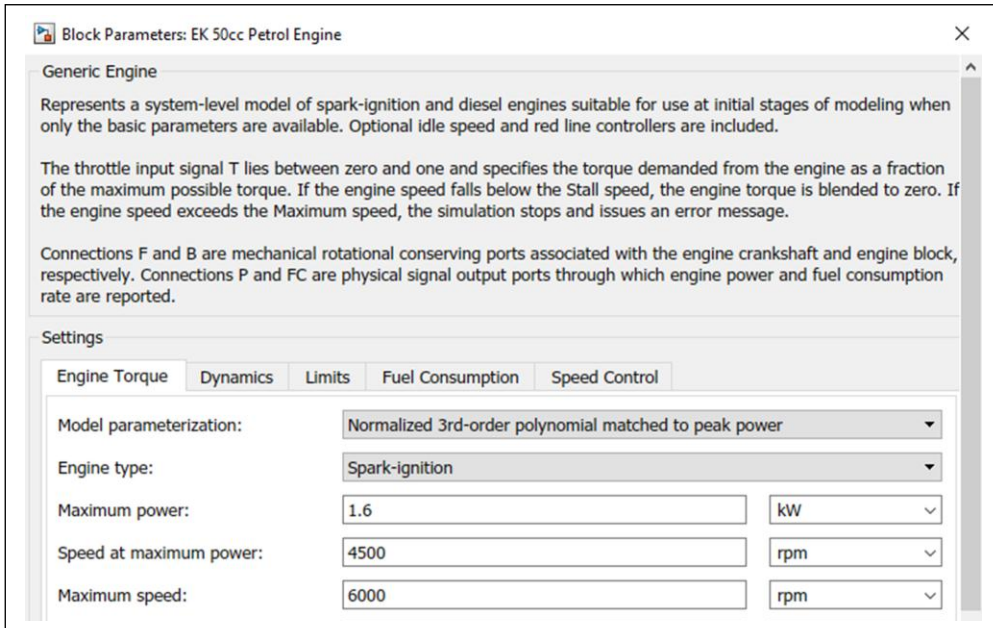
The throttle signal from the signal builder block is fed to the input port T, of the generic engine to power the engine. The throttle signal is also fed to the longitudinal driver speed input port which outputs an acceleration or deceleration signal, depending on the nature of the throttle signal. The electric motor receives input torque for rotation from the internal combustion engine. During deceleration, the motor implements regenerative braking by converting the input torque to back emf, which is fed to the battery with the help of the charge controller block. This results in an increase in the battery state of charge.

The diagram illustrates the flow process of the simulation.

Fig 3-10: Flow process of the simulation



3.3.9 Input Parameters



The engine parameters were set to the actual engine specifications

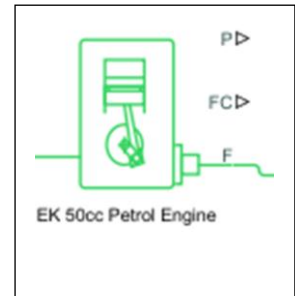


Fig 3-11: Block parameters for ic-engine

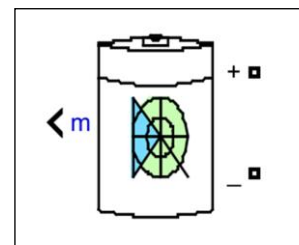
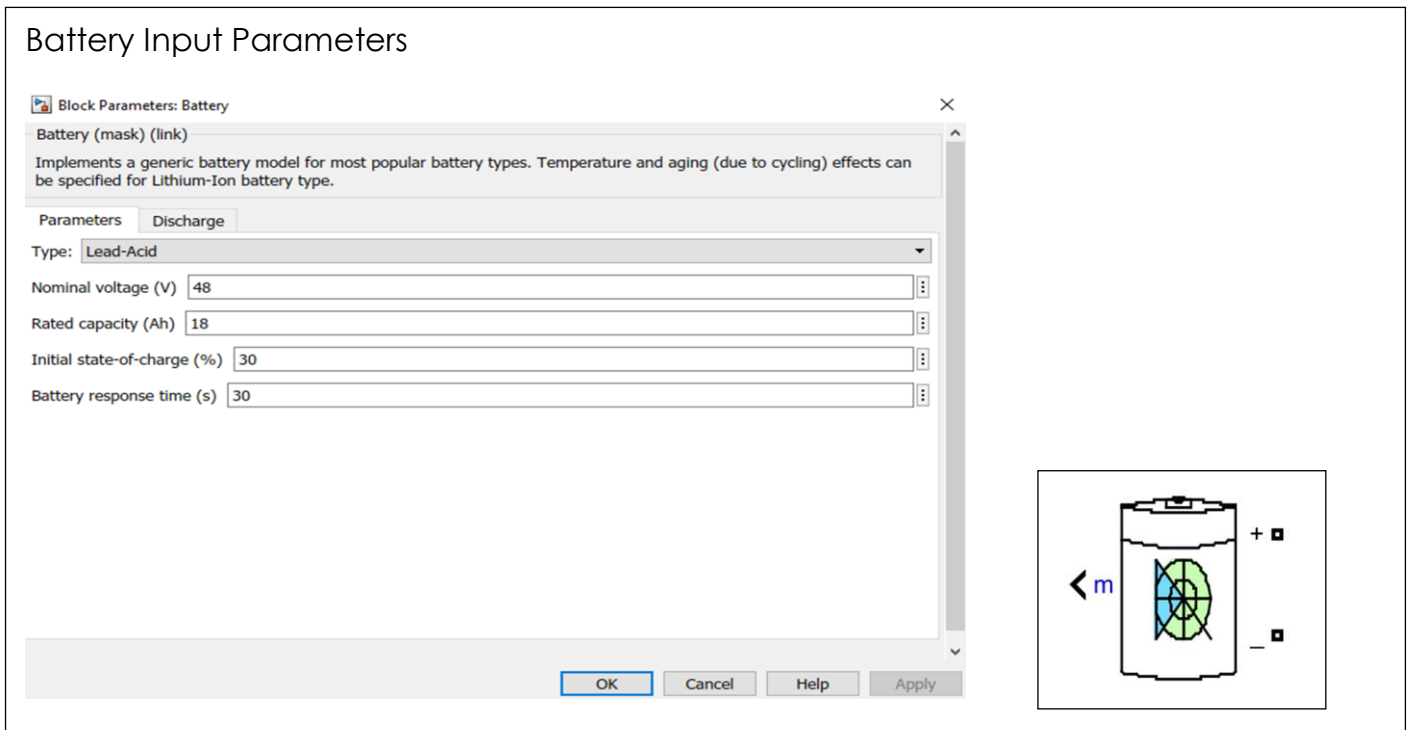
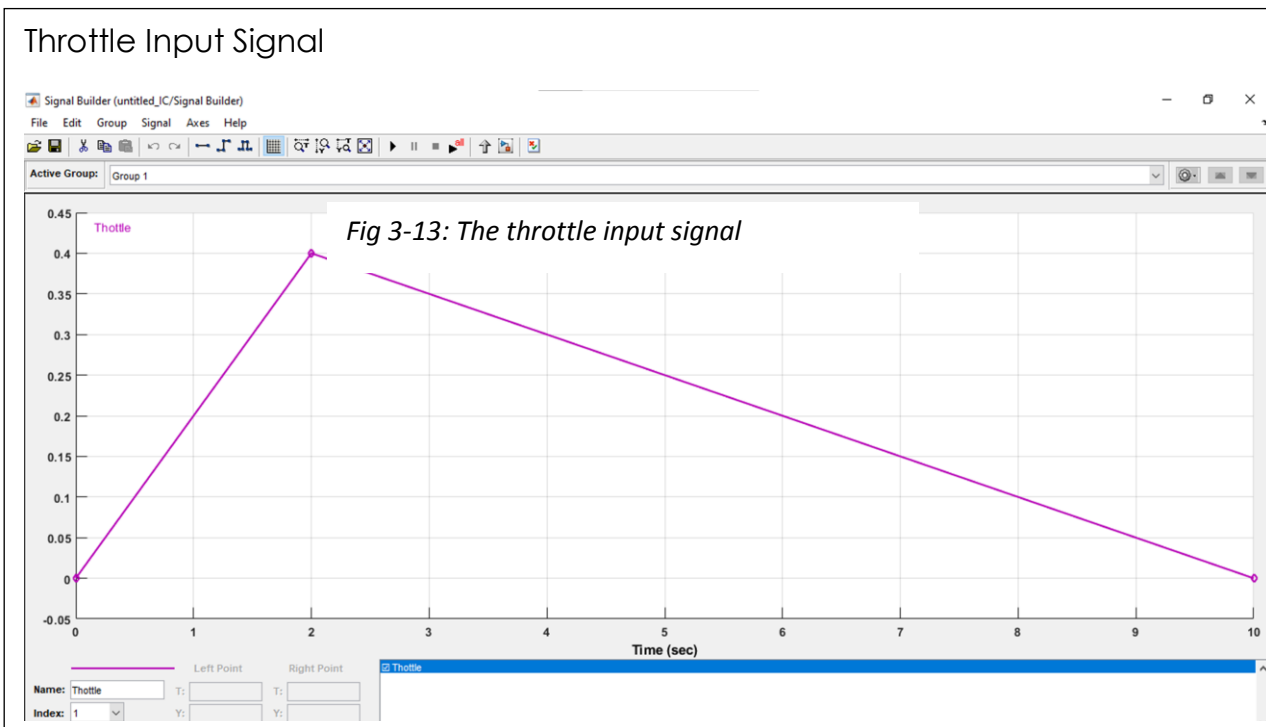


Fig 3-12: The Battery input parameters

The battery percentage was assume to be initially at 30% before regenerative braking occurred



3.4.1 Assumptions

1. The effect of drag is neglected
2. The vehicle is assumed to move through the still air
3. The body is assumed to be a point mass

3.4.2 Parameters

Vehicle mass (vehicle + driver), $M = 150\text{kg}$ Top speed for EM, $V = 15\text{km/hr}$
 (4.12m/s) Acceleration time, $t = 10\text{s}$ Maximum incline angle, $\theta = 3^\circ$ Working
 surface = concrete Coefficient of rolling resistance, $C_{rr} = 0.01$

3.4.3 Calculations

From equation 1.2, neglecting air drag, the traction force is given by

$$F_t = M \alpha + MgC_{rr}\cos\theta + Mgsin\theta$$

From the kinematic equations of motion,

$$\text{Acceleration, } \alpha = \frac{\Delta V}{t}$$

$$\therefore \text{Traction force, } F_t = M \left(\frac{\Delta V}{t} + gC_{rr}\cos\theta + g\sin\theta \right)$$

$$= 150 \left(\frac{4.12}{10} + 9.81 \times 0.01 \times \cos 3^\circ + 9.81 \times \sin 3^\circ \right)$$

$$\therefore \text{Traction force, } F_t = 153.5\text{N}$$

The braking power, P_b required to overcome this force over a distance, D of 9m in
 2 seconds is given as

$$P_b = \frac{F_t \times D}{T}$$

$$P_b = \frac{153.5 \times 10}{2}$$

$$= 690.75\text{W}$$

Therefore, the least rating for the electric motor to achieve such braking action should be 690.7

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Simulation results When Vehicle is in the electric Mode

4.1.1 For INPUT Modal Drive Cycle

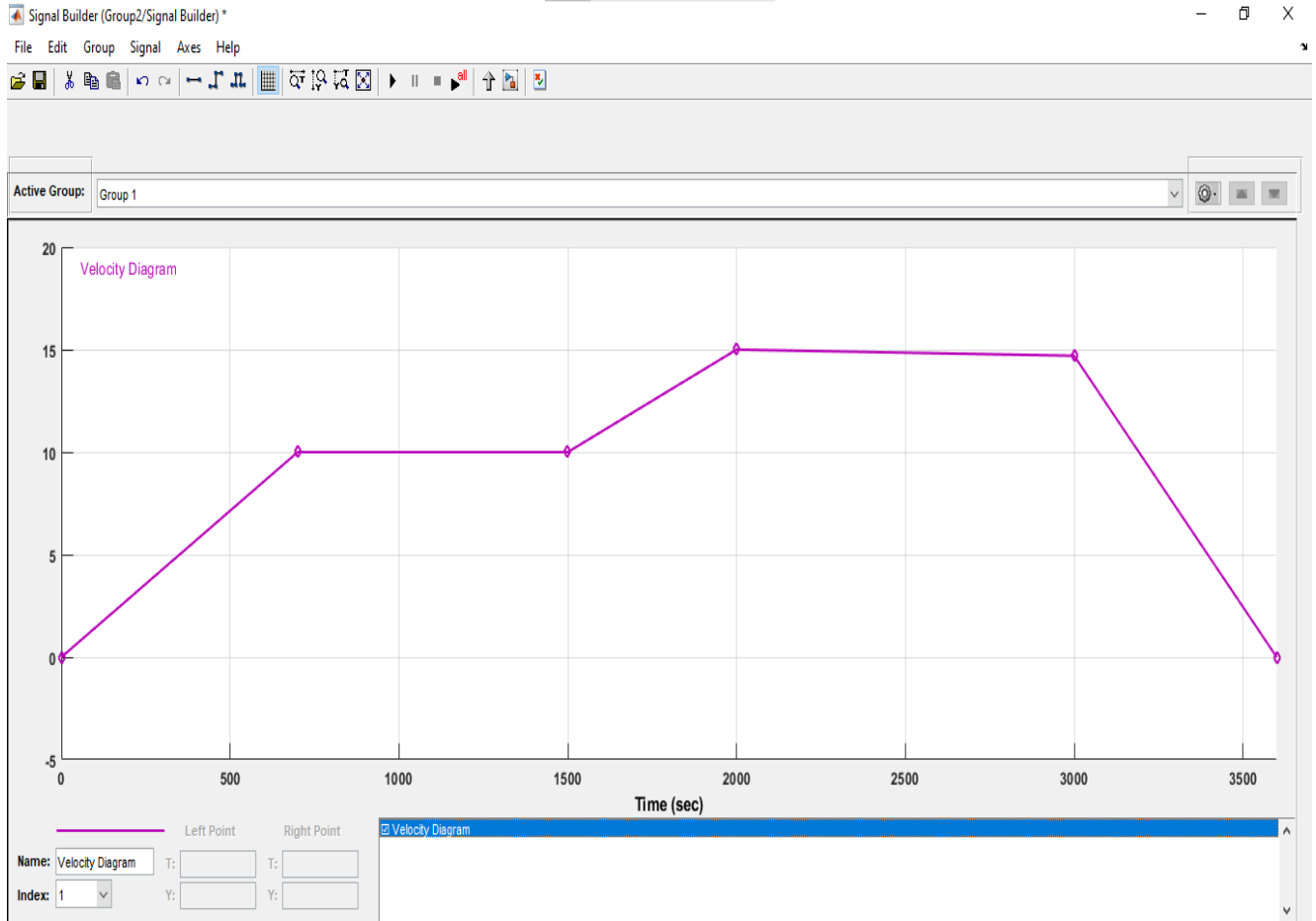
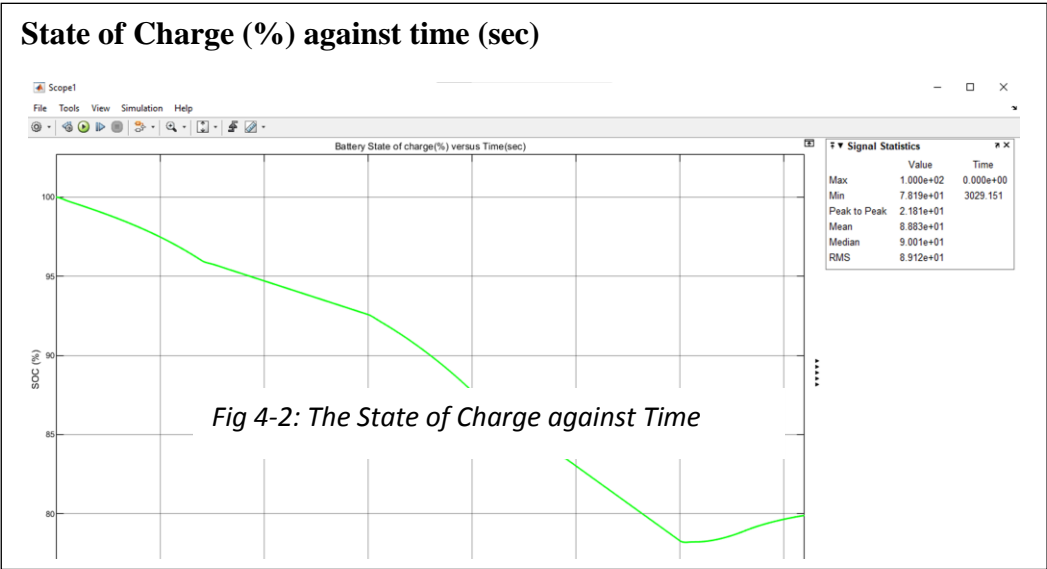
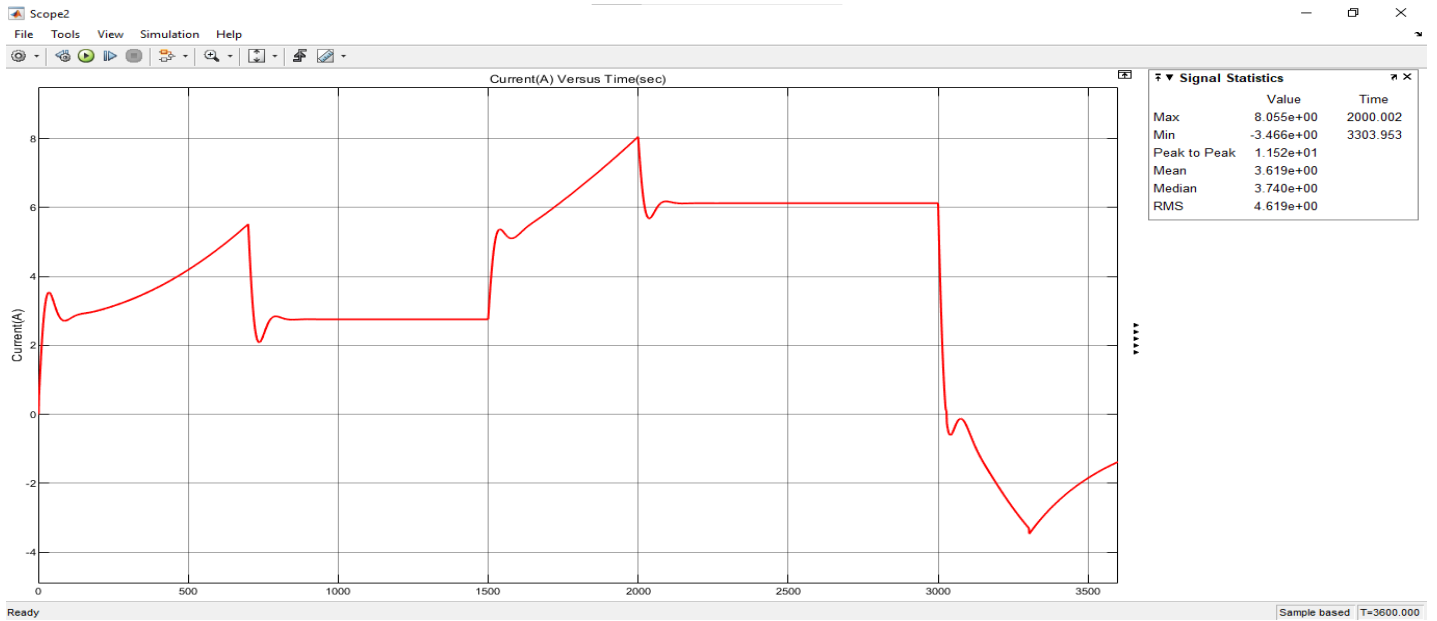
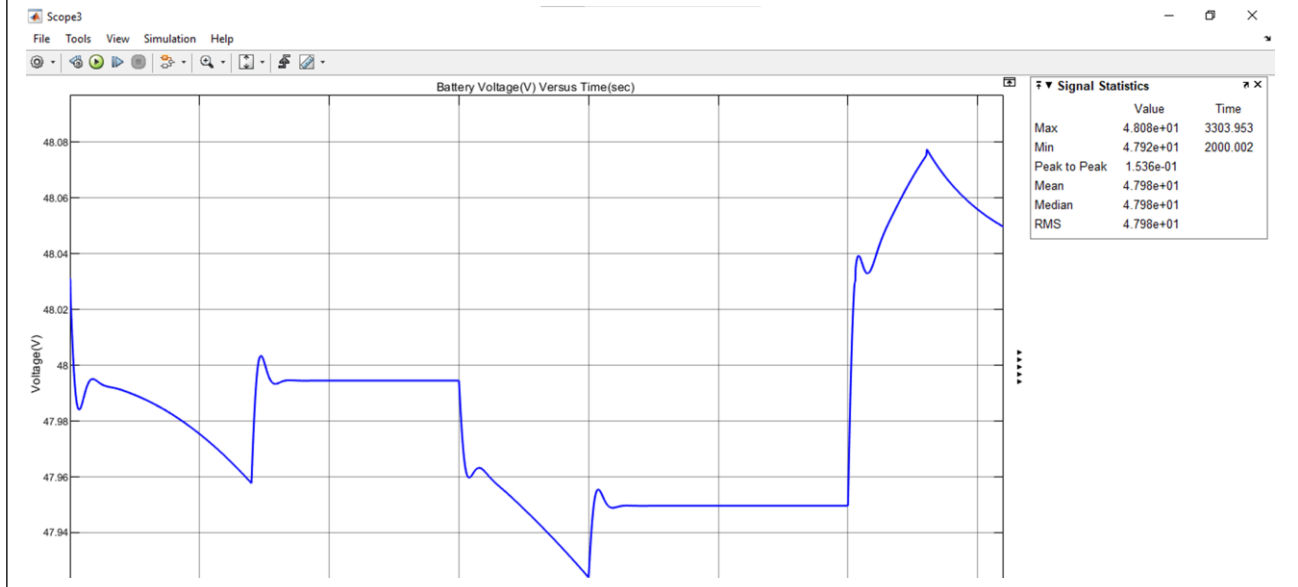


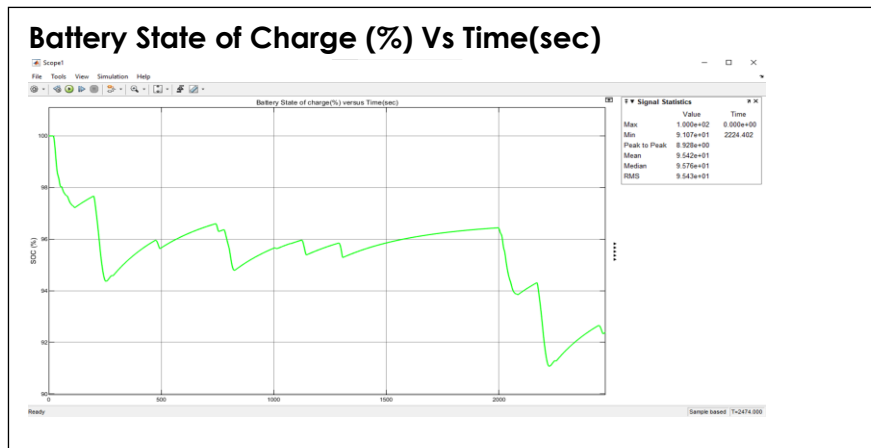
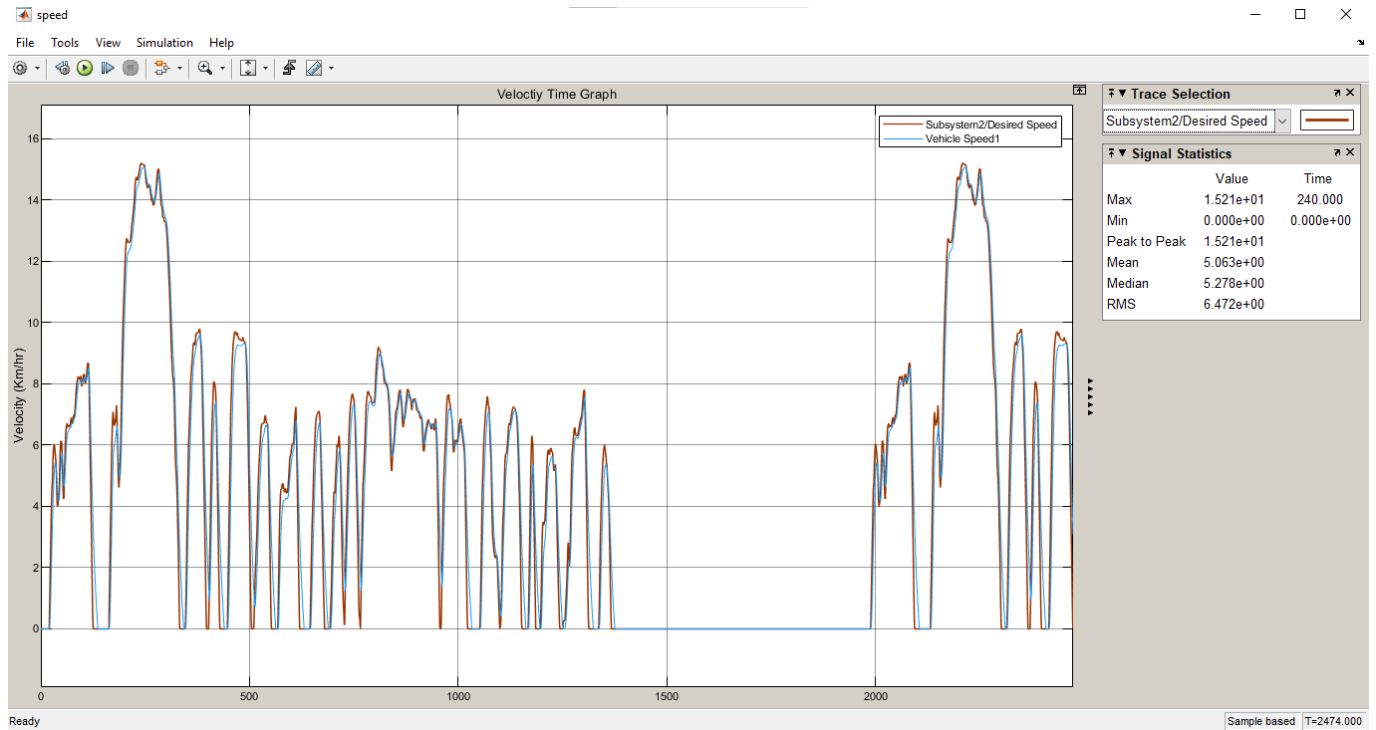
Fig 4-1: The Velocity-Time graph of the UFFa_19 series in a particular location

The simulation result for a modal cycle of the UFAA hybrid vehicle are shown below.



Battery Voltage(V) against Time(sec)





4.1.2 Discussion

From the simulation result observed in the 3000-3600 seconds of the drive cycle; The vehicle undergoes deceleration. During this period the battery state of charge increased from 78.19% to 80%, while the battery voltage increased from 47.93

volts to 48.05 volts. Also current flow in the reverse direction (having negative values due to back e.m.f) to charge the battery.

4.1.2 For Transient Drive Cycle FTP75

Current(A) drawn from battery against time (sec)

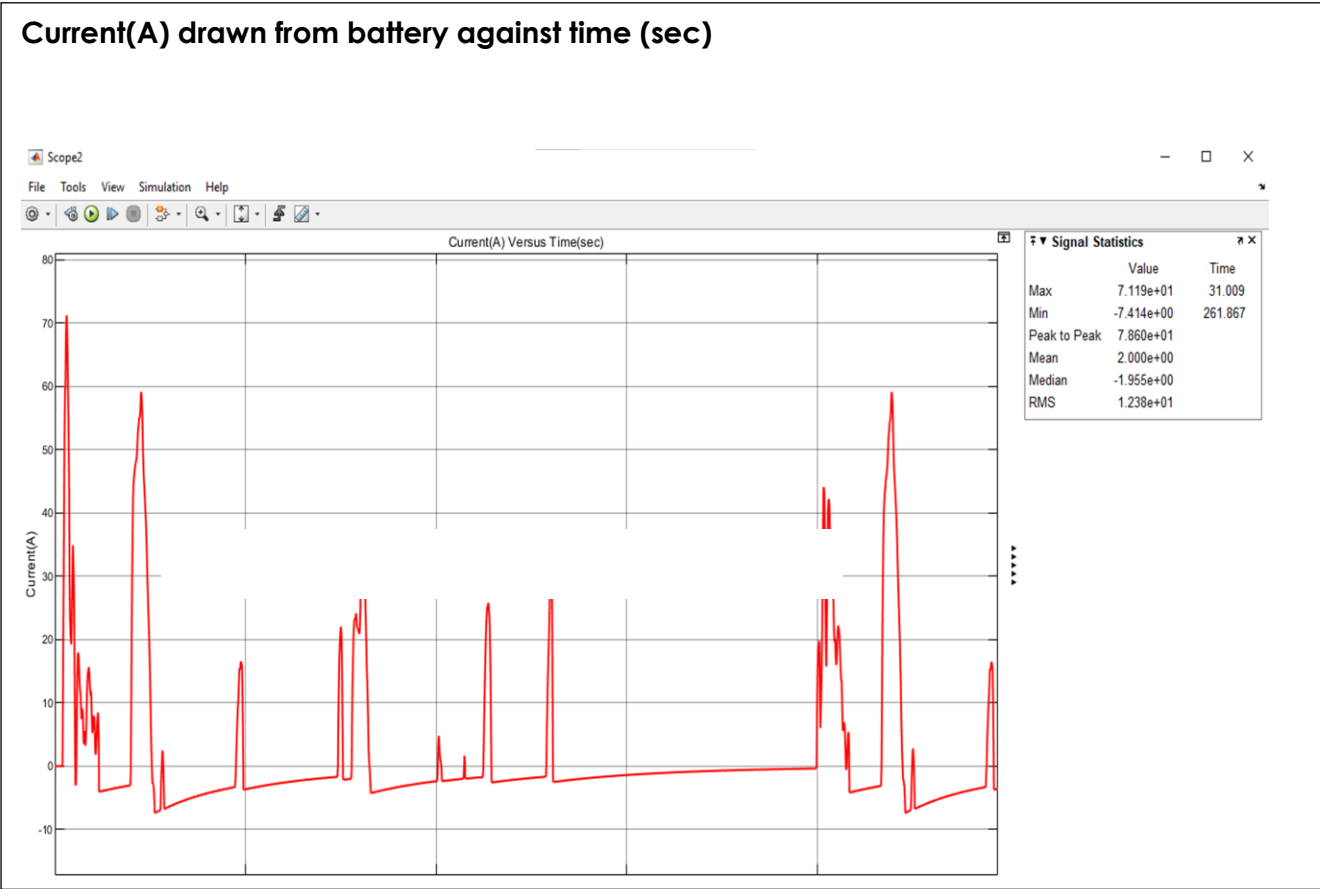


Fig 4-6: The Current drawn from battery against Time

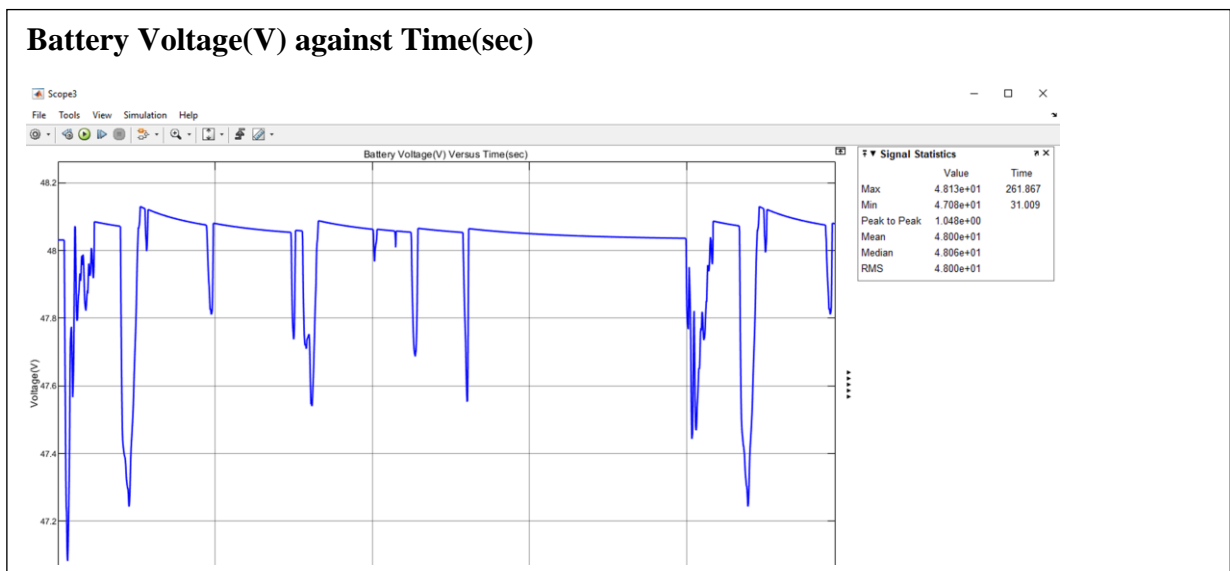


Fig 4-6: The Battery Voltage against Time

4.1.3 Discussion

This drive FTP75 drive cycle possesses series of acceleration and deceleration. This result is series of regenerative braking as observed from the battery state of charge. From the signal statistics, the lowest SOC is 91.07%, but due to regenerative braking the mean SOC is 95.42%.

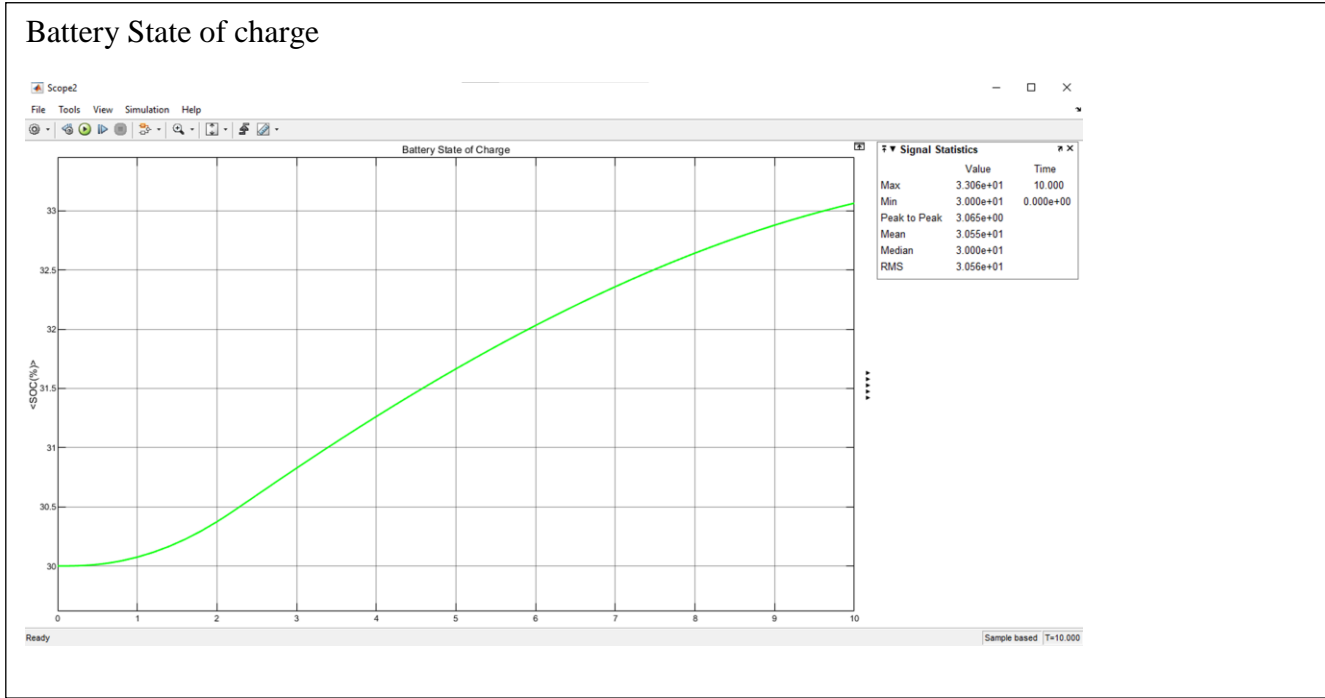


Fig 4-6: The Battery state of Charge

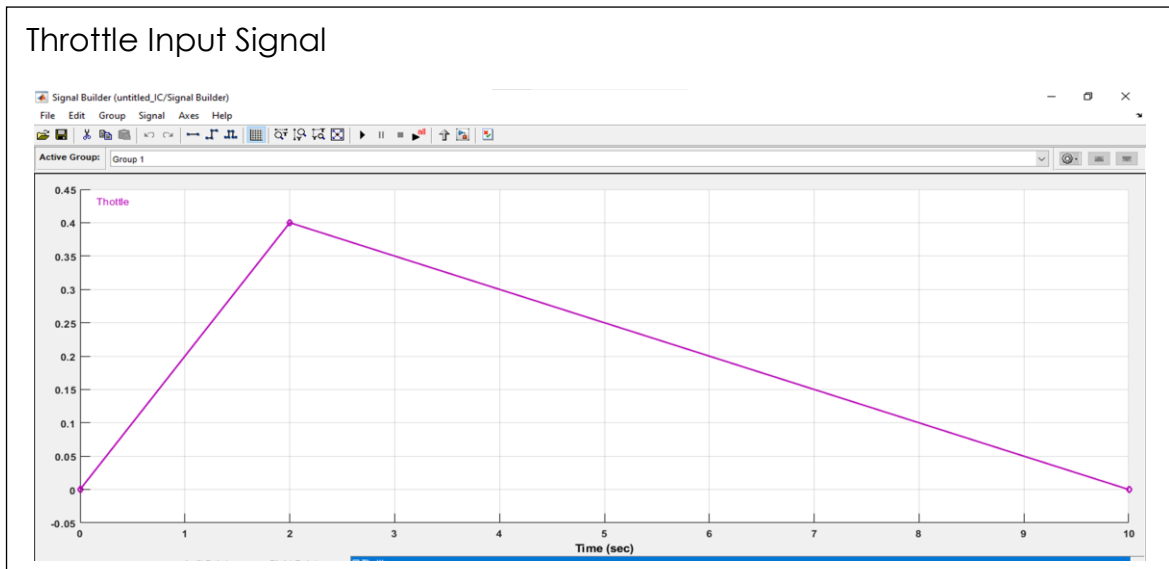
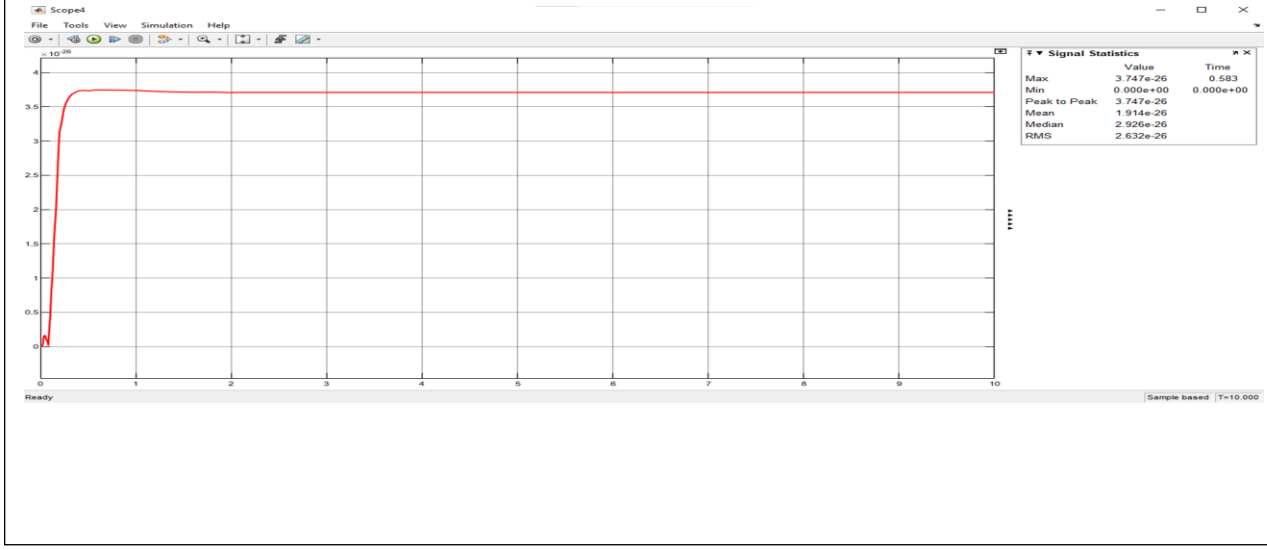


Fig 4-6: The Throttle Input Signal

Fuel Consumption During Regenerative Breaking Vs Time



Battery Voltage(V) Versus Time(sec)

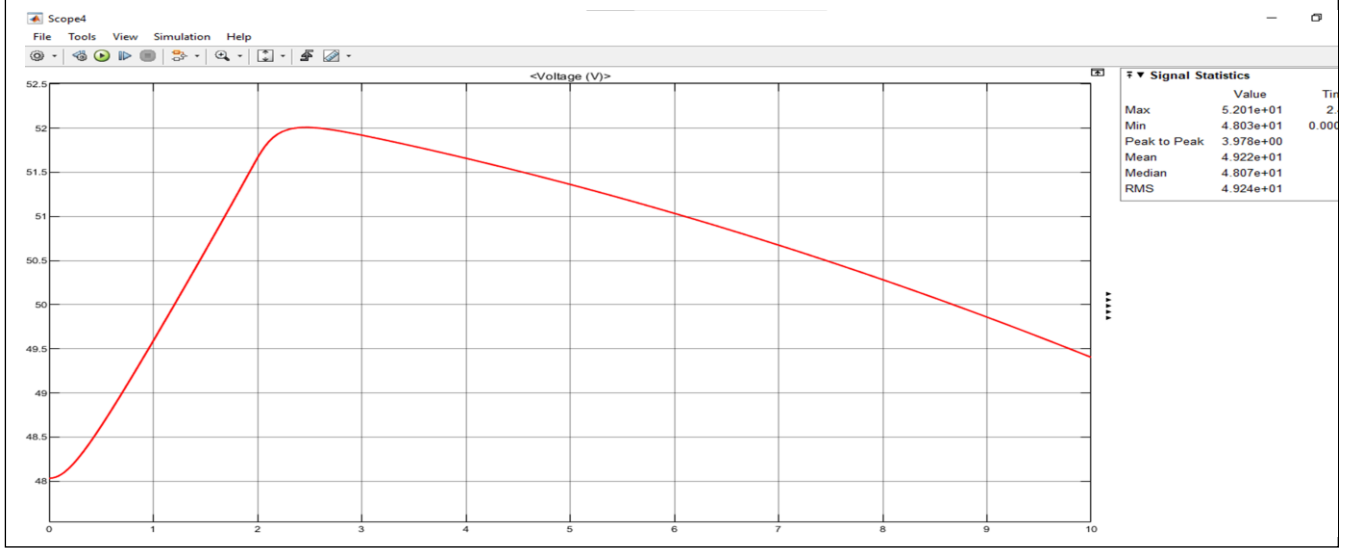


Fig 4-6: The Battery Voltage against Time

4.2.1 Discussion

From the simulation results, It is seen that during regenerative braking fuel consumption is minimal (about 43% conserved), while the battery state of charge increases from its initial 30% to 33%

CHAPTER 5

5.1 CONCLUSION

The aim of this project is to design a braking system for the UFAA-19 series Hybrid electric vehicle that utilizes regenerative braking so as to minimise fuel consumption thereby reducing the emission of carbon dioxide.

From the dynamic analysis and simulation conducted it is seen that there is about 43% fuel conservation and a 750Watt brushless motor will serve this purpose when connected in parallel to an internal combustion engine with a power rating of 1600Watts.

5.2 RECOMMENDATION

1. Building a physical model according to the following criteria and running it on a standard track while using the FTP-75 as the reference driving cycle should validate the simulation's results.
2. It is important to calculate and contrast the hybrid's fuel savings and overall efficiency with that of the IC system operating on its own.
3. It is recommended that the series-parallel hybrid and complex hybrid cars be examined, with the findings from this study being compared.
4. Testing should be done on further regenerative braking systems that use flywheels.

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