

A Project Report on
MODELING AND SIMULATION OF AN ELECTRIC VEHICLE

Submitted in a partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

in

ELECTRICAL AND ELECTRONICS ENGINEERING

by

Swathi Thotakura

Suguna Krishna Mohan

Sai Sudheer Neelam

Sravani Mopidevi

Under the Esteemed Guidance of

Mr. B. JAYA BABU, M. Tech (Ph. D)

Associate Professor



DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

VIGNAN 'S' LARA INSTITUTE OF TECHNOLOGY AND SCIENCE

(An ISO 9001:2015 Certified, Approved by AICTE, Affiliated to JNTUK, KAKINADA)

VADLAMUDI-522 213. GUNTUR District, ANDHRA PRADESH, 2020-2021

VIGNAN'S LARA INSTITUTE OF TECHNOLOGY AND SCIENCE

(An ISO 9001:2015 Certified, Approved by AICTE, Affiliated to JNTUK, KAKINADA)

VADLAMUDI-522213,

GUNTUR Dist., ANDHRA PRADESH.

Department of Electrical and Electronics Engineering



C E R T I F I C A T E

This is to certify that this dissertation entitled as “**MODELING AND SIMULATION OF ELECTRICAL VEHICLE**” is the bonfire work of, T. Swathi (17FE1A0286), S. Krishna Mohan(17FE1A0283), N. Sai Sudheer (17FE1A0273), M. Sravani (18FE5A0218), submitted to the Department of Electrical and Electronics Engineering, **VIGNAN'S LARA INSTITUE OF TECHNOLOGY AND SCIENCE** in partial fulfilment of the requirements for the award of the Degree in Bachelor of Technology in Electrical and Electronics Engineering.

Project Guide

Head of the Department

Mr. B. Jaya Babu
(Associate. Prof)

Mr. M. V. Sudarshan
(Associate. Prof)

DECLARATION

We, the students of Vignan's Lara Institute of Technology and Science, Vadlamudi, Guntur District, Andhra Pradesh, here by declare that this project work titled as "**MODELING AND SIMULATION OF AN ELECTRIC VEHICLE**" submitted to the Department of Electrical and Electronics Engineering of this institute, affiliated to Jawaharlal Nehru Technological University, Kakinada, for the award of Degree in Bachelor of Technology in Electrical And Electronics Engineering is a record of bonfire work done by us under the guidance of Mr. B. Jaya Babu, MTech(Ph.D.). Associate professor, Department of Electrical and Electronics Engineering at "**VIGNAN'S LARA INSTITUTE OF TECHNOLOGY & SCIENCE**" and it has not been submitted to any other institute or university for the award of any other Degree.

Place: Vadlamudi

Date:

Signatures of students with Roll numbers:

T. Swathi (17FE1A0286)

S. Krishna Mohan (17FE1A0283)

N. Sai Sudheer (17FE1A0273)

M. Sravani (18FE5A0218)

ACKNOWLEDGEMENT

It is to be acknowledged to the following who has helped, guided and encouraged for the successful completion of the project work.

We acknowledge and express our sincere thanks and deep sense of gratitude to the beloved chairman **Dr. LAVU RATHAIAH GARU** and the college management for providing us such a nice environment and good facilities for successful completion of the project.

We express our sincere thanks to **Dr. K. PHANEENDRA KUMAR**, principal of Vignan's Lara Institute of technology and science, Vadlamudi, for providing us an excellent environment for doing this project.

We express our sincere thanks and deep sense of gratitude to our head of the department, **Mr. M.V. SUDARSAN**, MTech,(Ph. D) for his patience and guidance that enabled us to complete the project work.

We would like to express deep sense of gratitude to our guide **Mr. B. JAYA BABU**, MTech (Ph. D) Associate professor, Department of Electrical and Electronics Engineering, Vignan's Lara Institute of Technology and Science, Vadlamudi for her eminent guidance, co-operation in completion of this project work.

We are indebted to our faculty members, parents and friends for their co-operation and encouragement throughout the completion of this project.

CONTENTS

	TITLE	Pg. No
	Declaration	i
	Acknowledgements	ii
	Contents	iii-vi
	List of Figures	vii-viii
	List of Tables	ix
	List of Abbreviations	x
	Nomenclature	xi
	Abstract	xii
CHAPTER- 1	INTRODUCTION	1-9
1.1	Project Background	1-2
1.1.1	Objective	2-3
1.2	Description of Electric Vehicle	4
1.3	E.V Parts and their functions	5
1.3.1	Batteries	5-6
1.3.2	Electrical Motor	6-7
1.3.3	Power Converter	7-8
1.3.4	Drive Controller	8

1.3.5	Drive Cycle	8
1.3.6	Vehicle Body	9
1.4	Summary	9
CHAPTER- 2	LITERATURE REVIEW	10-15
2.1	Introduction	10
2.2	Review on Papers	10-15
2.3	Summary	15
CHAPTER- 3	ANALYSIS OF VEHICLE BODY	16-21
3.1	Introduction	16
3.2	Physical Vehicle Body	16-17
3.2.1	Tire	18-19
3.2.2	Gear	19-20
3.2.3	Motor	20-21
3.3	Summary	21
CHAPTER- 4	ANALYSIS OF POWER CONVERTER AND BATTERY	22-27
4.1	Introduction	22

4.2	Power Converter	22
4.2.1	H-Bridge Power Converter	22-24
4.3	Pulse Width Modulation Technique	24-25
4.4	Solver Configuration	25
4.5	Battery	25-27
4.5.1	State of Charge	27
4.6	Summary	27
CHAPTER-5	ANALYSIS OF DRIVE CONTROLLER AND DRIVE CYCLE	28-31
5.1	Introduction	28
5.2	Drive Controller	28
5.2.1	Longitudinal Driver	28-29
5.3	Drive Cycle	29-30
5.4	Summary	31
CHAPTER- 6	SIMULATION AND RESULTS	32-39
6.1	Model and chosen tools	32
6.2	Simulink Circuit of Transmission system	32
6.2.1	Description on Circuit of Transmission System	33

6.3	Simulink Circuit of Control system	33
6.3.1	Description on Circuit of Control system	34
6.4	Simulink Circuit of SOC	34
6.4.1	Description of Circuit of SOC	35
6.5	Simulink Circuit of Electric Vehicle	35
6.5.1	Description on Circuit of Electric Vehicle	35
6.6	Results	36-39
6.7	Summary	39
CHAPTER- 7	CONCLUSION	40
7.1	Conclusion	40
7.2	Future Work	40
REFERENCES		41-42

LIST OF FIGURES

Figure No	Figure Name	Pg. No
1.1	Parts of Electric Vehicle	4
1.2	Basic Battery Circuit	5
1.3	DC Motor	6
1.4	Power Converter	7
1.5	Basic Circuit of H-Bridge	7
1.6	Physical Vehicle Body	8
3.1	MATLAB Model of Vehicle Body	16
3.2	MATLAB Model of Tire	16
3.3	MATLAB Model of Gear Box	17
3.4	MATLAB Model of DC Motor	18
4.1	MATLAB Model of H-Bridge	20
4.2	MATLAB Model of PWM	21
4.3	MATLAB Model of Battery	22
5.1	MATLAB Model of Controller Driver	25
5.2	Drive Cycle Path	26
6.1	Simulation Circuit of Transmission system	28
6.2	Simulation Circuit of Control system	29

6.3	Simulation Circuit of SOC	30
6.4	Simulation Circuit of Electrical Vehicle	31
6.5	Result on Speed of Vehicle	32
6.6	Result on Distance of Vehicle Travel	33
6.7	Result on Battery State of Charge	34
6.8	Result on Currents Drawn by the Motor	35

LIST OF TABLES

Table No.	Table Name	Pg. No
1	The Effect of Different Gear Boxes and Energy Consumption	1
2	Comparison of Batteries with their Properties	5
3	Block Parameters of Physical Vehicle Body	17
4	Block Parameters of Tire	18
5	Block Parameters of DC Motor	21
6	Block Parameters of H-Bridge	23
7	Block Parameters of PWM	24
8	Block Parameters of Battery	26

LIST OF ABBREVIATIONS

SYMBOL		ABBREVIATIONS
EVs	-	Electric Vehicles
GHG	-	Green House Gases
RES	-	Renewable Energy Sources
CO ₂	-	Carbon Dioxide
HEV's	-	Hybrid Electric Vehicles
BEV's	-	Battery Electric Vehicles
PHEV's	-	Plug-in Hybrid Electric Vehicles
DC	-	Direct Current
IC	-	Internal Combustion
PWM	-	Pulse Width Modulation
REF	-	Reference
BRK	-	Brake
REV	-	Reverse
SOC	-	State of Charge
V _{nom}	-	Nominal Voltage
PI	-	Proportional Integral
ZVS	-	Zero Voltage Switching
ZCS	-	Zero Current Switching

NOMECLATURE

SYMBOL	NAME	UNITS
V	Voltage	Volts(V)
V_{nom}	Nominal Voltage	Volts(V)
VelRef	Reference Velocity	m/s
VelFdbk	Feedback Velocity	m/s
a	Acceleration	m/s^2
d	Deacceleration	m/s^2
Vel	Velocity	m/s
N	Speed	m/s
m	Mass	Kg
W	Weight	N
T	Time	Sec
I	Current	A
G	Gravity	$N Kg^{-2}m^2$

ABSTRACT

In this project we are presenting the simulation and modelling of a basic electrical vehicle motor-drive system that is used to investigate power flow during both motoring and regeneration. The simulation assumes a DC permanent magnet motor. Electric vehicles are necessary in the shift away from combustion engine vehicles in order to reduce the transport sectors greenhouse gas emissions. Unlike vehicles with combustion engines, electric vehicles need to be charged, a process that takes variable duration of time depending on the power generated by the solar energy. Electric vehicles are likely to be an alternative energy mode of transportation for the future as it has shown a great ability to reduce the consumption of petroleum based and other high CO₂ emitting transportations fuels. So, this project focuses on a step-by-step design procedure which is the estimation of the ratings of different components in an Electric Vehicle powered. Physical modelling approach has been used for vehicle modelling to improve the modelling efficiency. Regenerative braking control is also been employed at the time of deceleration so that the kinetic energy is not wasted as heat. As some amount of it can be recovered and used for charging the battery, which can increase the Electric vehicle travel range.

CHAPTER-1

1. INTRODUCTION

1.1 Project background:

The first electric vehicle was produced by Thomas Parker in 1884, 25 years after the invention of lead-acid batteries. After that date, many electric vehicle models appeared. However, the development of internal combustion engine technology and the reduction in mass production costs have left electric vehicles behind.

The energy crisis that lived between 1970 and 1980 brought electric vehicles back to the forefront. But they could not reach the high speeds and long ranges of conventional vehicles. For this reason, sufficient technological development could not be achieved.

Until today, many companies have produced electric vehicles. However, the range of these vehicles is short and they cannot reach high speeds. With the development of electric motor and battery technology, longer distance vehicles have begun to be produced. The time it takes to charge the battery is very high, despite the extended range of ranges. For this reason, electric vehicles are still not at the desired level.

T. HOFMAN and C.H.DAI, the effect of different gearboxes on energy consumption has been investigated. The powertrain system has been investigated using fixed gear system, manual gearbox and CVT gearbox.

S.no	Gearbox Type	NEDC	FTP75
1	Fixed Gear	1.58	2.81
2	Manual	1.62	3.31
3	CVT	1.59	3.14

Table 1. The Effect of Different Gearboxes and Energy Consumption

A. Kerem, as electric vehicle technology in the world develops, interest in electric vehicles will increase. This shows that environmental pollution will decrease and dependence on petrol will decrease.

O. Vatan, modelling of an electric vehicle with MATLAB/Simulink. The model has a 30-kWh battery. This vehicle in the city consumes 0.58 kWh/100km and 0.44 kWh/100km outside the city. The vehicle has a max range of 52-70 kilometres.

E. Schaltz, designed and modelled an electric vehicle. This vehicle consumes 148.3 Wh/km of energy. Also explains that a large part of the energy loss is caused by the auxiliary loads, the lighting system, the security systems, the comfort systems and the battery.

X. D. Xue, tried to determine the appropriate electric motor for electric vehicles. Electric motors were compared according to efficiency, cost, safety and weight criteria. The study concludes that the permanent magnet synchronous motor is the best motor type.

E. Baser, an electric vehicle model with two motors, an asynchronous motor and a permanent magnet synchronous motor. As a result of the work the asynchronous motor at low speeds and the synchronous motor at constant speed with high speed are more efficient.

1.1.1Objective:

Any automobile that is propelled by an electric motor, using energy stored in a battery is known as a Pure Electric Vehicle or Battery Electric Vehicle commonly known as Electric Vehicles. Battery electric vehicles store electricity onboard with high-capacity battery packs. Their battery power is used to run the electric motor and all onboard electronics. Electric Vehicles do not emit any harmful emissions and hazards. BEVs are charged by electricity from an external source using electric Vehicle (EV) chargers. Electric vehicles (EVs) are one of a prominent solution for the sustainability issues needing dire attention like global warming, depleting fossil fuel reserves, and greenhouse gas (GHG) emissions. Conversely, EVs are shown to emit higher emissions (measured from source to tailpipe) for the fossil fuel-based countries, which necessitates renewable energy sources (RES) for maximizing EV benefits. EVs can also act as a storage system, to mitigate the challenges associated with RES and to provide the grid with ancillary services, such as voltage regulation, frequency regulation, spinning reserve, etc. For extracting maximum

benefits from EVs and minimizing the associated impact on the distribution network, modelling optimal integration of EVs in the network is required.

Why Electric Vehicles?

Internal combustion engines have been dominating as the propulsion source of automobiles since a long term, hence the exploitation on fossils have increased drastically, which is getting depleted. The idea of propulsion of automobiles using electric motors came to light from early 19th century itself. Hence to compensate for fossil depletion, reducing pollution levels and as an alternate and more efficient source propulsion, demand for Electric Vehicles is expected to increase drastically. Electric vehicles are expected to be the most dependent source of transport in near future. With technological advancements in semiconductor devices, the control of motors is also now simpler and highly efficient operation of Electric Vehicle can be achieved.

Global warming is one of the greatest challenges the humanity has ever faced, and the core of the issue is reducing the CO₂ emissions in the near future. One of the most promising technologies to reduce CO₂ emissions produced by the transport sectors are Electric Vehicles (EV_s). These are vehicles that replace the combustion engine with an electrical motor.

Generally, there are 3 different types of electrical vehicles:

- ❖ Hybrid electrical vehicles (HEV's).
- ❖ Battery electric vehicles (BEV's).
- ❖ Plug-in hybrid vehicles (PHEV's).

PHEVs are charged by either plugging into electric outlets or by means of on-board electricity generation. In a BEV, batteries store the electrical energy in an electro-chemical reaction for later use. So, we charge these batteries to run the vehicle.

Our final moto is of making a model of BEV and simulation of it, to estimate the efficiency of the electric vehicle for different drive cycles and to get the esteem knowledge on state of the charge and the distance that can be covered.

1.2 Description of an Electric Vehicle:

The electric vehicle (EV) is propelled by an electric motor, powered by rechargeable battery packs, rather than a gasoline engine. From the outside, the vehicle does not appear to be electric. In most cases, electric cars are created by converting a gasoline-powered car. Often, the only thing that clues the vehicle is electric is the fact that it is nearly silent. Under the hood, the electric car has:

- 1) An electric motor
- 2) A controller
- 3) A rechargeable battery.

The electric motor gets its power from a controller and the controller gets its power from a rechargeable battery. The electric vehicle operates on an electric/current principle. It uses a battery pack (batteries) to provide power for the electric motor. The motor then uses the power (voltage) received from the batteries to rotate a transmission and the transmission turns the wheels. Four main parts make up the electric vehicle: the potentiometer, batteries, direct current (DC) controller, and motor

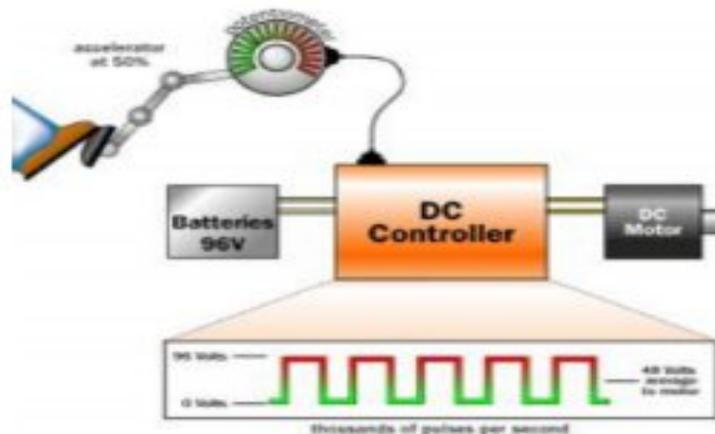


Fig 1.1: Parts of Electric Vehicle

1.3 E.V Parts and their Functions:

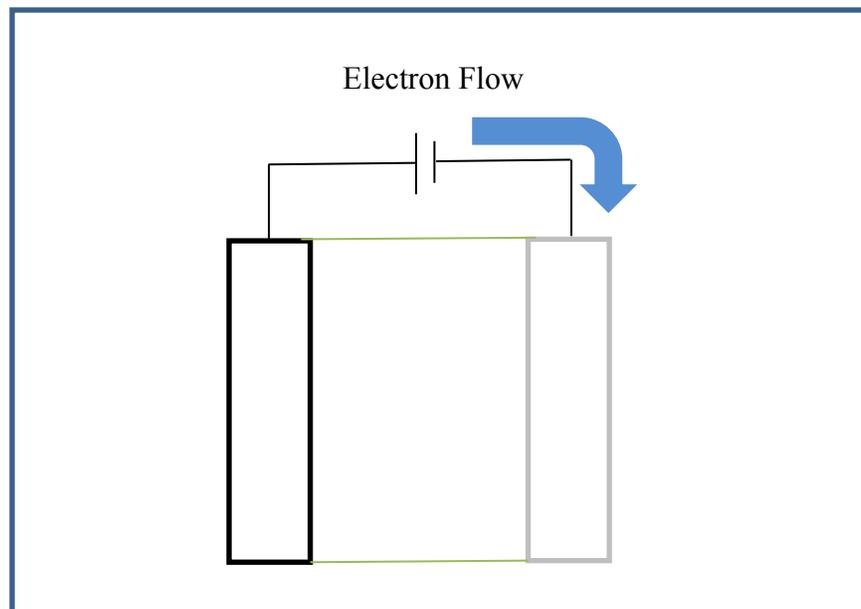
1.3.1 Batteries:

The batteries provide power for the controller. Three types of batteries:

1. lead acid
2. lithium ion
3. nickel-metal hydride batteries

Basically, battery works on the principle of operation of converting chemical energy directly into electrical energy. In many cases, the electrical energy is released based on the difference in cohesive/bond energy of the metals, oxides, or molecules undergoing the electro chemical reaction. Batteries are designed so that the electrical favourable redox reactions can only occur when electrons move through the external part of the circuit.

The voltage developed across a cell or battery terminals depends on the energy release of the chemical reactions of the electrodes (Anode, Cathode) and Electrolyte. Alkaline and Zinc-Carbon batteries have different chemistries but produces an approximately the same emf/voltage of 1.5 volts, like-wise NiMh and some other batteries have different chemistries, as mentioned in the Table-2.



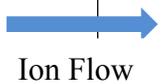
Items	Lead Acid Batteries Anode	Electrolyte	NiMh Batteries Cathode	Li-ion Batteries
Voltage(V)	2.0		1.2	3.3-3.7
Specific Energy (Wh/L)	100-200		100-200	300 - 400+
Life time(cycles)	300 - 500		500 - 1000+	800 - 1500+
Cost	Low		Medium	High

Fig-1.2: Basic Battery Circuit

Table 2: Comparison of Batteries with their Properties

1.3.2 Electrical Motor:

An Electric Motor is an electrical machine which converts electrical energy into mechanical energy. Most electric motors operate through the interaction between the motor's magnetic field and the electric current in a wire winding to generate force in the form of torque applied on the electric motors.

- DC Motors can be operated at variable speeds by adjusting DC voltage applied to the terminals or by using Pulse Width Modulation (PWM).
- A.C motors can be operated at both fixed and variable speeds. The motors working with fixed speed are generally powered directly from the grid, while the motors working with variable speed are powered with variable power-invertors, variable frequency drives or even with electronic commutator technology.

Here we are using DC motor over AC motor as per the ease of adjustments in the supply voltage.

DC Motor:

DC motors were the first form of motor widely used, as they could be powered from existing direct-current lighting power distribution systems. A DC motor's speed can be controlled over a wide range, using either a variable supply voltage or by changing the strength of current in its field windings. Small DC motors are used in tools, toys, and appliances. The universal motor can operate on direct current but is a lightweight brushed motor used for portable power tools and appliances. Larger DC motors are currently used in propulsion of electric vehicles, elevator and hoists, and in drives for steel rolling mills.

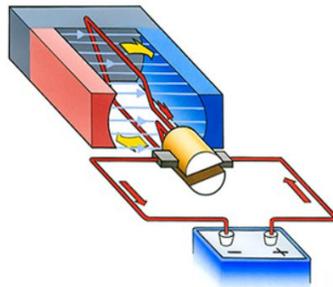


Fig 1.3: DC Motor

1.3.3 Power Converter:

A power converter is an electrical circuit that changes the electric energy from one form into the desired form optimized for the specific load. A converter may do one or more functions and give an output that differs from the input. It is used to increase or decrease the magnitude of the input voltage, invert polarity, or produce several output voltages of either the same polarity with the input, different polarity.

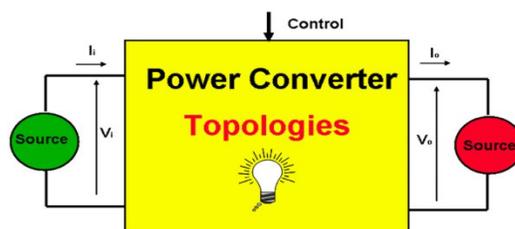


Fig 1.4: Power Converter

H-Bridge Converter:

The H-bridge arrangement is generally used to reverse the polarity/direction of the motor, but can also be used to 'brake' the motor, where the motor comes to a sudden stop, as the motor's terminals are shorted, or to let the motor 'free run' to a stop, as the motor is effectively disconnected from the circuit.

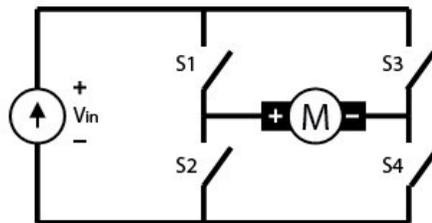


Fig 1.5: Basic Circuit of H – Bridge

1.3.4 Driver Controller:

A parametric longitudinal speed tracking controller for generating normalized acceleration and braking commands based on reference and feedback velocities. In simple we can say it as a Driver to drive the vehicle. The drive controller we use is a longitudinal driver controller.

1.3.5 Drive Cycle:

A driving cycle is a series of data points representing the speed of a vehicle versus time. Driving cycles are produced by different countries and organizations to assess the performance of vehicles in various ways, as for instance fuel consumption, electric vehicle autonomy and pollution emissions.

Generally, these drive cycles are used for the purpose of test to get the performances of fuel consumption and emissions of a chassis dynamo meter. Another use for these cycles is, in vehicle simulation. More specifically they are used in propulsion system simulations, to predict the performances of internal combustion engine, transmissions, electric drive systems.

1.3.6 Vehicle Body:

Vehicle body is most expensive part of a car. Vehicle body is the main supporting structure of a vehicle, to which all other components are attached. The vehicle body has H-Hub, S-Tire Slip, N-Normal Force, A-Axel connection, V-Velocity, W-Wind velocity, beta - Inclination angle.

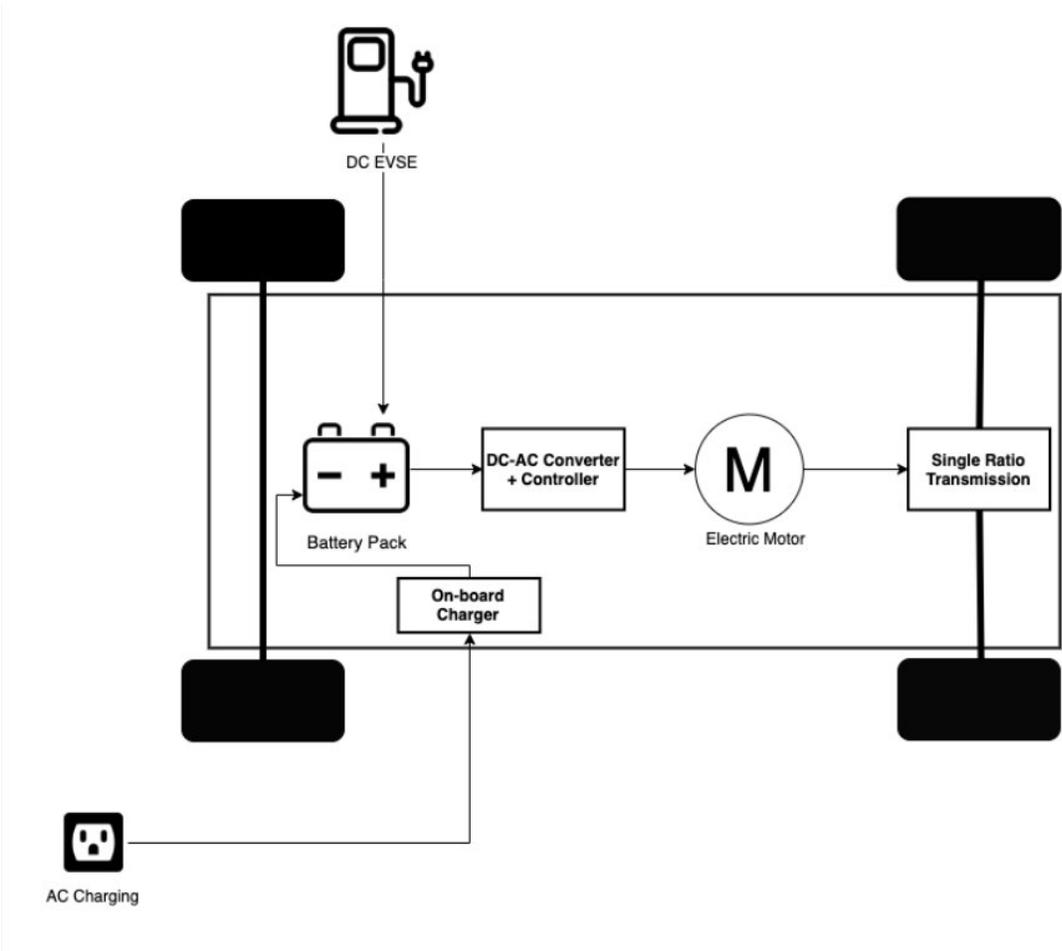


Fig 1.6: Physical Vehicle Body

1.4 Summary:

In this section we have examined about Project Background, Objectives of the venture and Description of Electrical Vehicle Parts and their Functions. Significant parts in this Electrical Vehicle are Battery, Electrical Motor, Power Converter, Drive Controller and Drive Cycle.

CHAPTER-2

LITERATURE REVIEW

2.1 Introduction:

In this chapter we are presenting the review on the papers we had gone through. We considered these also highlighted the positives and negatives of each paper.

1. Modelling and Simulation of Battery Electric Vehicle by Using MATLAB Simulink
2. Electric Vehicle Designing, Modelling and Simulation
3. Modelling Large Electric Vehicle Fleets in Power System Simulations
4. PV based Electric Vehicle Modelling in the Distribution Network

2.2 Reference Papers:

Paper-1:

A.A. Abulifa & R.K. Raja Ahmad

“Modelling and Simulation of Battery Electric Vehicle by Using MATLAB Simulink”

One of the greatest challenges that is facing the environment in the world is energy saving. Our global energy environment as well faces many difficulties. Although no one knows accurately the future of the energy, we still believe that transportation will play a major role in saving the future energy. Today, Electric Vehicles (EVs) are one of the technological progress results that have contributed and continue to contribute in order to make our lives easier and safer. Because EVs do not only consume energy, but they also produce, store, and transport electricity. That is what makes them an excellent alternative for the fuel vehicles. Moreover, they are more economical and eco-friendlier compared with the traditional cars that use gasoline or diesel fuel because they have a reversible energy storage device. In this study, MATLAB-Simulink was used in order to design the BEV components and integrating the whole system. Moreover, it was used

to simulate the BEV model and its equations. This paper discussed the simulation of the BEV, its relevant electrical system components and its corresponding equation for verification. In addition, it examines all simulation results. The BEV components are Transmission, Electric Motor, Battery Charge Controller, Driving Cycle, Driver Model and Longitudinal Vehicle Dynamic Model. MATLAB-Simulink used to design the battery electric vehicle components and integrating the whole system. Moreover, MATLAB-Simulink used to simulate the battery electric vehicle and its corresponding equation for verification. MATLAB is a technical computing language that assimilates programming, computation and visualization in one environment. It has been improved in order to solve engineering and scientific problems and it is used now in many different domains. MATLAB has a powerful and rich graphic toolbox that enables the user to work in an easy and comfortable environment. In this study, BEV and its components have been simulated in order to investigate the energy flow, performance and efficiency. Good results for Battery Voltage, Current, Power, and State of charge were shown by using MATLAB-Simulink. A lot of chances still ahead in order to establish better BEV model that will be the basis for further future researches. With the purpose of finding the best voltage, current, power, state of charge for the battery and the exact component size, and to minimize the use of energy, modelling and simulation are very essential for automotive designers.

Paper 2:

Sai Krishna Vempalli & J. Ram Prabhakar

“Electric Vehicle Designing, Modelling and Simulation”

In present days Air borne pollution became a serious problem in the metropolitan cities. Even the Indian capital Delhi had faced the problem of smog which is mainly due to internal combustion engine vehicles. The ODD and EVEN car number policy which is, allowing the Even and odd car plate numbered vehicles to roam in the city on alternate days didn't show much impact or didn't alleviate the air borne pollution to much extent. Like this many cities in the world are facing the same problem which made the way for the Electric vehicles in the automotive market. Tesla motors the pioneer company in the manufacturing of Electric vehicles brought a revolution in the EV market, uses Induction motor for propulsion of their vehicles as they are rugged and cheaper than Permanent Magnet machines. For an Electric vehicle design the pivotal part is estimating the parameters of various components like battery rating, motor rating, gear ratio etc. Selection of the type of motor depends on various factors like cost, efficiency, ruggedness reliability, torque capability etc. Depending on the vehicle application like whether it needs high speed or high range the battery composition should be taken (i.e.) some Li-ion chemistries will have high discharge rates, some Li-ion chemistries will have fire safety like Lithium titanate batteries. Range anxiety is one of the deciding factors in case of an Electric vehicle whose accuracy depends on accurate estimation of state of charge (SOC). Basic EV system with Field oriented motor control and regenerative braking control is modelled and simulated in Simulink environment. Battery charging at the time of regenerative braking and acceleration time of the vehicle from 0 – 60 Km/h is observed from the simulation model output.

Paper 3:

Levin Skiba & Albert Moser

“Modelling Large Electric Vehicle Fleets in Power System Simulations”

The need to reduce total greenhouse gas emissions leads to an increase in suitable efforts in all sectors. Therefore, in the transportation sector, a growing number of electric vehicles is expected. A rising number of electric vehicles also increases the electric load, which in turn increases demand on electricity markets. Depending on the time of charging processes, higher peak loads and a rising demand for flexibility could be the consequence. At the same time, electric vehicles and the possibility to shift their charging processes could counter this rising demand for flexibility or even enable the vehicles to provide flexibility for the grid. In order to study problems like this, market simulations are frequently used. In that context or for other types of power system simulations, adequate modelling of electric vehicles becomes indispensable. Therefore, firstly, this paper discusses implications of modelling large numbers of individual electric vehicles in power system simulations. Subsequently, we propose a way to model aggregated vehicle classes to circumvent possible problems adequately considering relevant restrictions. We use exemplary investigations in a market simulation to validate our model. The results indicate that the proposed model is suitable to represent large fleets of electric vehicles in power system simulations. Market simulations are one possible approach to do so. For this purpose, optimization problems are constructed, aiming at minimizing total generation costs while covering electric load with available generation capacity and considering technical restrictions. Depending on the geographic and temporal scope as well as on technical restrictions considered, these optimization problems can take on considerable sizes.

Paper 4:

Asaad Mohammad, Ramon Zamora

“PV based Electric Vehicle Modelling in the Distribution Network”

The issues like global warming, depleting fossil fuel reserves, and greenhouse gas (GHG) emissions need dire attention for ensuring a sustainable future. Because the transportation sector is one of the largest contributors to the rising harmful emissions, the electrification of transportation is seen as a promising solution for this problem. Electric vehicle (EV) technology has existed for more than a century peaking commercially around 1900. However, due to the easy availability of fossil fuels, advancements in internal combustion (IC) technology, and simplicity in the use of IC engines, EVs were put on hold and limited to golf carts and delivery vehicles. Figure 1 shows the progression timeline of the EVs. The dependency on petroleum imports for transportation purposes is also reduced by electrification of transportation, thereby increasing energy security. However, the adoption rate of EVs remains slow owing to factors, such as high initial cost, battery degradation, inadequate charging infrastructure, range anxiety, etc. Various policies and incentives are made available by governments around the world to promote the uptake of EV and to prevent these barriers from realizing a complete shift to electrified transportation. As per the report “Global EV outlook” of the International Energy Agency, the total number of EVs are projected to reach 130 million by 2030. However, high penetration of EVs also poses distribution network quality issues, particularly network congestion, three-phase voltage imbalance and off-nominal frequency problems. The EVs are a mobile single-phase load so they can be randomly plugged in at any one of three phases within distribution networks, leading to a scenario that electrical components in one particular phase, such as power supply cable, overhead line or transformer may be heavily loaded while the rest of two phases are not. The unbalanced three-phase loading may lead to a series of negative impact on power quality issue: Transformer failures, equipment loss-of-life, relay mis function, etc. Moreover, as EVs are highly spatial and

temporally uncertain, handling EVs as additional loads while maintaining the reliability and security of the grid is difficult. The coincidence of timing between EV home charging and residential load peaks leads to additional system peaks. Moreover, multiple EV chargers in a neighbourhood can introduce significant harmonics, thereby reducing power quality. Therefore, the integration of substantial EV penetration in the distribution networks is a significant area of interest in the research and engineering community, especially optimally controlling EV charging to minimise the impact of the above-described issues. Another significant contributor to harmful emissions is the power industry, particularly fossil fuel-based power generation. Renewable energy sources (RES), such as wind and solar are increasingly adopted to mitigate the power industry emissions.

2.3 Summary:

In this section we have examined around four distinct papers identified with Electric Vehicles. From those papers we are gathering some data and utilize that information in this task and furthermore we are added some more methods.

CHAPTER-3

VEHICLE BODY MODELLING

3.1 Introduction

In the chapter we are going to give brief discussion about modelling of the vehicle body.

These are the parts used to model a complete vehicle a body which is the major building block of the entire modelling of an electric vehicle. The major parts used in the modelling of vehicle body are as follows;

1. Physical Vehicle Body
2. Tires
3. Gear box
4. Motor

3.2 Physical Vehicle Body

The first model of the vehicle body is discovered on January 29, 1886 by **Karl Benz**, in his invention on gas engine model. The year 1886 is regarded as the birth year of the modern car when German inventor Karl Benz patented his **Benz Patent-Motorwagen**. Development started as early as the 17th century with the invention of the first steamed-powered vehicle, which led to the creation of the first steam-powered automobile capable of human transportation, built by **Nicolas-Joseph Cugnot** in 1769. Inventors began to branch out at the start of the 19th century, creating the **de Rivas Engine**, one of the first internal combustion engines, and an early electric motor.

The physical vehicle body is the major part of entire vehicle which holds the engine or motor, battery, seats, gear box and so on.

The physical vehicle body which we used is a mat lab simulation block. It represents a two-axle vehicle body in motion. Accounts for body mass, aerodynamic drag, externally defined mass and inclination road angle. It consists of two input ports as well as three output ports. The vehicle body mass, aerodynamic drag values can be modified.

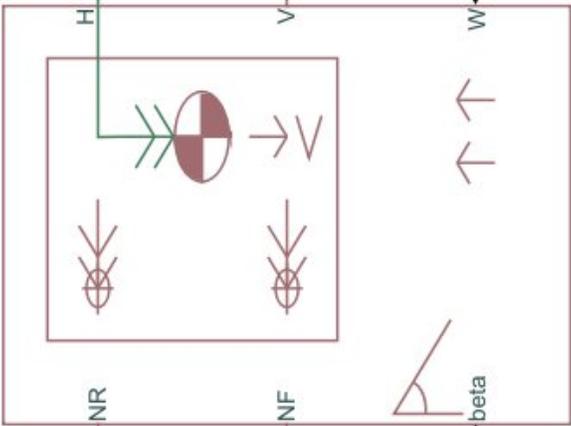


Fig 3.1: MATLAB Model of Vehicle Body

Block Parameters	Values	Units
Mass	800	Kgs
Number of wheels per Axle	4	-
Horizontal Distance from CG to Front Axle	1.4	m
Horizontal Distance from CG to Rear Axle	1.6	m
CG height above ground	0.5	m
Gravitational Acceleration	9.81	m/s ²

Table 3: Parameters of Physical Vehicle Body

3.2.1 Tire:

A Tire is a ring-shaped component that surrounds a wheel's rim to transfer a vehicle's load from the axle through the wheel to the ground and to provide traction on the surface over which the wheel travels.



Fig 3.2: MATLAB model of Tire

Block Parameters	Values	Units
Rated Vertical Load	3000	N
Peak Longitudinal Force at rated Load	3500	N
Slip at Peak Force at rated Load (%)	10%	-
Rolling Radius	0.48	mm
Constant Coefficient	0.015	-

Velocity Threshold	0.001	m/s
--------------------	-------	-----

Table 4: Block Parameters of Tire

Here we are using mat lab simulation block. Used to model a tire with longitudinal behaviour given by equation based on four fitting coefficients. The block can model tire dynamics under constant or variable contact surface conditions. In this block we are having four terminals, They are:

N - Normal force acting on tire, Positive when force is acting downwards/towards the contact surface

S - Slip value relative to tire and surface of contact

H – Represents wheel hub which transmits thrust generated by the wheel to the body of the vehicle

A – Represents axle on which the tires are mounted

Nominal load and radius of tires are modified. Rolling resistance is kept at default values and dynamics depends on default damping and stiffness values of the tire.

3.2.2 Gear:

Gears are mechanical parts with cut teeth designed to fit with teeth on another part so as to transmit or receive force on motion.

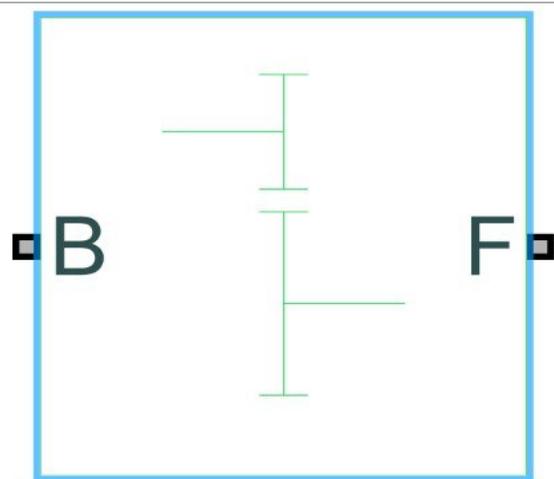


Fig 3.3: MATLAB Model of Gear Box

A Simple gear block is used to connect the motor to the rear axle of the vehicle. It represents the gearbox which connects the input shaft to the base gear and output from the follower gear. In this block we are having two ports,

B – port associated with input shaft (motor shaft)

F – port associated with output shaft (axle/differential)

Gear ratio and output direction is modified. Meshing loss is kept constant and gear is having a constant efficiency throughout the simulation. Viscous losses and faults are kept at default conditions.

3.2.3 Motor:

An electric motor is an electrical machine that converts electrical energy into mechanical energy. Most electric motors operate through the interaction between the motor's magnetic field and electric current in a wire winding to generate force in the form of torque applied on the motor's shaft.

Here we considered DC MOTOR Which is an electrical block in MATLAB simulation. This block contains an Electrical motor coupled with a Mechanical rotor reference. This mechanical reference is the major part which connects the motor with the gear box, further which is connected to the tires of the body with physical body.

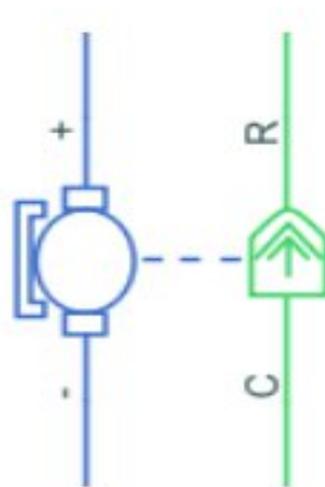


Fig 3.4: MATLAB Model of DC Motor

Block Parameters	Values	Units
Filed Type	Permanent Magnet	-
Armature Inductance	0.01	H
No Load Speed	7000	rpm
Rated speed (Rated load)	5000	rpm
Rated Load (Mechanical Power)	75	KW
Rated DC supply Voltage	240	V
Rotor Inertia	0.01	g*cm ²

Table 5: Parameters of DC Motor

3.3 Summary:

In this chapter we have discussed about how to construct a vehicle body and its parts such as, Tire, Gear and Motor and their functioning parameters.

CHAPTER- 4

MODELLING OF POWER CONVERTER AND BATTERY

4.1. Introduction:

In this chapter we are going to give brief discussion about Power converter. In this project we are using H-Bridge Converter as a power converter to convert one form of power into another form, In H-Bridge we are seeing Pulse width converter technique (PWM), Breaking Methodology. And also, in this chapter we are discussing about Battery.

4.2 Power Converter:

A power converter is an electrical circuit that changes the electric energy from one form into the desired form optimized for the specific load. A converter may do one or more functions and give an output that differs from the input. It is used to increase or decrease the magnitude of the input voltage, invert polarity, or produce several output voltages of either the same polarity with the input, different polarity.

4.2.1 H-Bridge Power converter:

H-Bridge is used to represent H-bridge motor driver which controls the power input to the motor according to the load requirements. Output provided by the block is controlled voltage depending on the control signal. In this H-Bridge converter block we are having six ports, there are

(+) - Conserving port associated with positive load connection usually connected to positive port of the motor

(-) - Conserving port associated with negative load connection usually connected to the negative terminal of the motor.

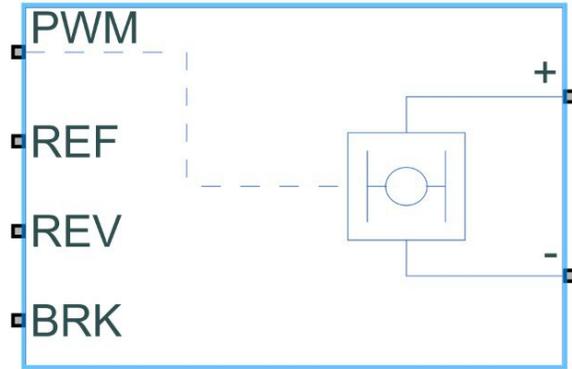


Fig 4.1: MATLAB Model of H-Bridge

Block Parameters	Values	Units
Output Voltage Amplitude	240	V
Total Bridge on Resistance	0.1	Ohm
Free Wheeling on Resistance	0.05	Ohm
Enable Threshold Voltage	2.5	V
PWM Signal Amplitude	5.0	V
Reverse Threshold Voltage	2.5	V
Braking Threshold Voltage	2.5	V

Table 6: Block Parameters of H-Bridge

PWM-Conserving port associated with PWM control signal (voltage pulses)

REF-Conserving port associated with a ZERO voltage reference.

REV-Conserving port associated with voltage controlling polarity change of Bridge output signal

BRK - Conserving port associated with voltage when brakes are applied thereby aiding the process of regenerative braking.

4.3 Pulse width Modulation Technique:

Pulse-width modulation (PWM) is a powerful technique for controlling analog circuits with a microcontroller's digital outputs. PWM is used in many applications, ranging from communications to power control and conversion. For example, the PWM is commonly used to control the speed of electric motors, the brightness of lights.

The PWM Block is used to produce Pulse-Width modulated signals to control voltage fed to H-Bridge as per requirements. The H-Bridge can be driven by the Controlled PWM Voltage block in PWM or Averaged mode. In PWM mode, the motor is powered if the PWM port voltage is above the Enable threshold voltage. In Averaged mode, the PWM port voltage divided by the PWM signal amplitude parameter defines the ratio of the on time to the PWM period. Using this ratio and assumptions about the load, the block applies an average voltage to the load that achieves the correct average load current. The Simulation mode parameter value must be the same for the Controlled PWM Voltage and H-Bridge blocks.

This PWM Block having four conserving ports, they are

ref+ - positive reference voltage signal port

ref- - negative reference voltage signal port

PWM – Pulse-width modulated electrical signal

REF – Port associated with ZERO voltage reference

Block Parameters	Values	Units
PWM Frequency	5000	Hz
Output Voltage Amplitude	240	V
Input Voltage for 100% Duty Cycle	5	V

Table 7: Parameters of PWM

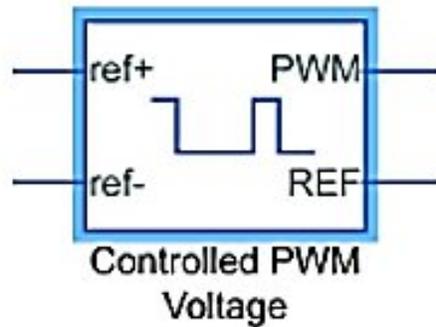


Fig 4.2: MATLAB Model of PWM

If the REV port voltage is greater than the Reverse threshold voltage, then the output voltage polarity is reversed. If the BRK port voltage is greater than the Braking threshold voltage, then the output terminals are short circuited via one bridge arm in series with the parallel combination of a second bridge arm and a freewheeling diode. Voltages at ports PWM, REV and BRK are defined relative to the REF port. If exposing the power supply connections, the block only supports PWM mode.

4.4 Solver Configuration:

A Solver configuration block specifies solver parameters necessary for simulation and is connected to the physical network of motor controller. In this block we are seeing a function as $f(x)=0$. This solver configuration block is connected with H-Bridge through REV terminal.

4.5 Battery:

A battery is a power source consisting of one or more electrochemical cells with external connections for powering electrical devices such as flashlights, mobile phones, and electric cars. When a battery is supplying electric power, its positive terminal is the cathode and its negative terminal is the anode. The terminal marked negative is the source of electrons that will flow through an external electric circuit to the positive terminal. When a battery is connected to an external electric load, a redox reaction converts high-energy reactants to lower-energy products, and the free-energy difference is delivered to the external circuit as electrical energy. Historically

the term "battery" specifically referred to a device composed of multiple cells; however, the usage has evolved to include devices composed of a single cell.

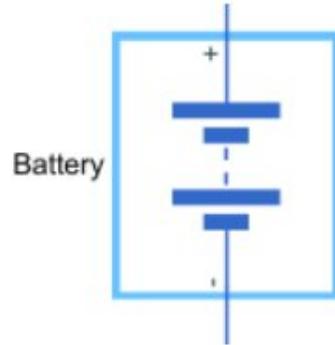


Fig 4.3: MATLAB Model of Battery

Block Parameters	Values	Units
Nominal Voltage (V_{nom})	240	V
Internal Resistance	0.02	Ohm
Ampere-hour Rating	80	hr*A
Voltage V1 when charge is AH1	170	V
Charge AH1 when no load Voltage is V1	10	hr*A

Table 8: Block Parameters of Battery

The battery is required to power the controller and motor. The controller uses the power accordingly to produce the input given by the motor to obtain maximum speed. The battery is also used to power every electrical component in the vehicle. The battery has two states, one is charging and another one is discharging. The charge is to be set as finite in order to get the appropriate results. Then the formula used to calculate the charge- dependent voltage as:

$$V = V_{nom} \times SOC \div [1 - beta \times (1 - SOC)]$$

Where: SOC - State of Charge

V_{nom} - Nominal Voltage

Beta - It is ratio of Charge of battery to voltage (initially)

4.5.1 State of Charge (SOC):

The state of charge (SOC) of a cell denotes the capacity that is currently available as a function of the rated capacity. The value of the SOC varies between 0% and 100%. If the SOC is 100%, then the cell is said to be fully charged, whereas a SOC of 0% indicates that the cell is completely discharged. In practical applications, the SOC is not allowed to go beyond 50% and therefore the cell is recharged when the SOC reaches 50%. Similarly, as a cell starts aging, the maximum SOC starts decreasing. This means that for an aged cell, a 100% SOC would be equivalent to a 75%–80% SOC of a new cell.

In the designed vehicle battery charge is calculated by giving it to the rate transition and then to gain of “1 / (Nominal Battery Capacity)” then to a discrete-time integrator and it will get deducted from “1” as it is considered as 100%.

4.6 Summary:

In this Chapter we have examined about how the power converter is valuable for electrical vehicle and what kind of Power converter we are utilizing that is H-Bridge converter and their benefits. Pulse Width Modulation Technique and about Battery additionally examined in this part.

CHAPTER – 5

MODELLING OF DRIVE CONTROLLER AND DRIVE CYCLE

5.1 Introduction:

In this chapter we are going to give brief discussion about Drive controller, which is used to control the vehicle speed by taking the inputs from the user or reference values. And also, in this chapter we are discussed about Drive cycle, it is a series of data points representing the speed of a vehicle versus time. Drive cycle basically is the representative of the road.

5.2 Drive Controller:

A Drive controller is a device or group of devices that can coordinate in a predetermined manner the performance of an electric motor. A motor controller might include a manual or automatic means for starting and stopping the motor, selecting forward or reverse rotation, selecting and regulating the speed, regulating or limiting the torque, and protecting against overloads and electrical faults. Motor controllers may use electromechanical switching, or may use power electronics devices to regulate the speed and direction of a motor. In this project we are using a longitudinal driver to control the vehicle.

5.2.1 Longitudinal Driver:

This Longitudinal Driver Represents a longitudinal speed controller which produces acceleration and deceleration commands based on input and feedback speed variables provided using a proportional integral (PI) control. This driver uses the external actions to input signals that can disable, hold, or override the closed-loop commands determined by the block. The block uses this priority for the input commands: disable, hold and override. In simple we can say it as a Driver to drive the vehicle. In this block we are seeing three input ports and three output ports. They are as follows;

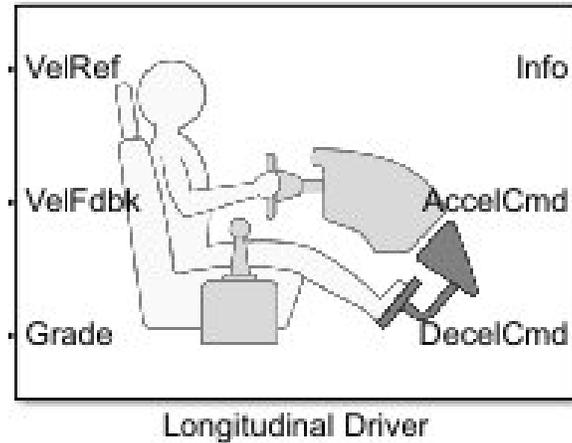


Fig 5.1: MATLAB Model of Controller Driver

Input Ports:

- VelRef - input port associated with input reference velocity of the vehicle (m/s)
- VelFdbk - input port associated with velocity feedback from the vehicle which helps in smooth control of the system.
- Grade - input port associated with inclination of surface in degrees.

Output Ports:

- Info - output port associated with a bus signal for acceleration, deceleration, error in velocity
- AccelCmd -Output port associated with acceleration commands with reference to input signal.
- DecelCmd -Output port associated with deceleration commands with reference to the input drive signal.

5.3 Drive Cycle:

The "Drive-cycle" basically is the representative of the road. Drive cycles are used to reduce the expense of on road tests, time of test and fatigue of the test engineer. The whole idea is to bring the road to the test lab or to the computer simulation. Two kinds of drive cycle can be

made. One is Distance dependent (Speed versus Distance versus Altitude) and the other one is Time dependent (Speed versus Time versus Gear Shift). The Distance dependant is the actual replica of the test road whereas Time dependent is the compressed version of the actual time taken to conduct the test on road.

This is a technique for prediction of future driving cycles and patterns for different types of vehicle applications. These cycles are used as an important input in designing and evaluating future power train systems and vehicle concepts. As of today, obsolete drive cycles are used during the design phase and due to this the changes in traffic conditions and infrastructure which has occurred during the last decade are not taken into account. Therefore, the need for new drive cycles representing today or the next few decades is great. This technique can predict future drive cycle by integrating available measurement data, high-fidelity traffic simulators and traffic models for heavy vehicles. Desirably, traffic simulation models are automatically generated and used to collect predicted drive cycles.

In this project we used Time vs speed data which resembles similar to that of a real-time driving conditions with acceleration and deceleration in an irregular pattern. By default, FTP75 drive cycle is selected. Wide-Open-Throttle condition can also be selected. Drive cycle data can also be taken from the spreadsheet data or through a glider block or a signal builder block. Simulation default time for FTP75 is 2474 seconds.

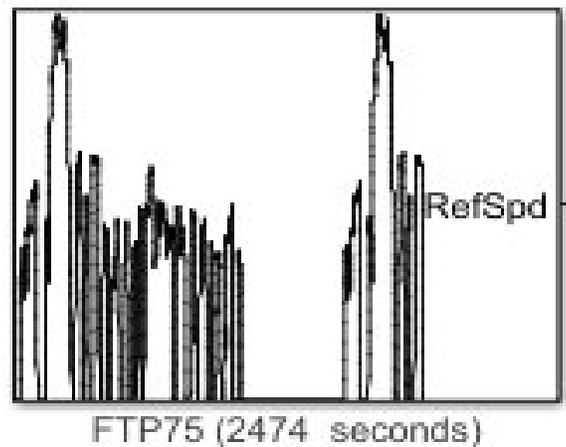


Fig 5.2: Drive Cycle Path

5.4 Summary:

In this chapter we have discussed about how the Drive controller works and what type of driver we used that is longitudinal driver. And also, we are discussed about Functioning of Drive Cycle, here we are using FTP75 Drive cycle.

CHAPTER-6

SIMULATION AND RESULTS

6.1 Models and chosen tools:

The model was made in Simulink and MATLAB, two integrated applications made by Math works. Simulink and MATLAB are chosen because they are powerful tools that provide different toolboxes and simulation blocks for electrical circuitry. Simulink has been used for several projects involving different battery powered systems. We can use Simulink and MATLAB to model a complete Electric Vehicle which was used for examining distance travelled and battery consumed by the vehicle for a specific path and time. The battery model in Simulink was used and also, we can examine how the battery reacts to different charging patterns. The top layer of the Simulink model is shown in Figure below.

6.2 Simulink circuit of Transmission System:

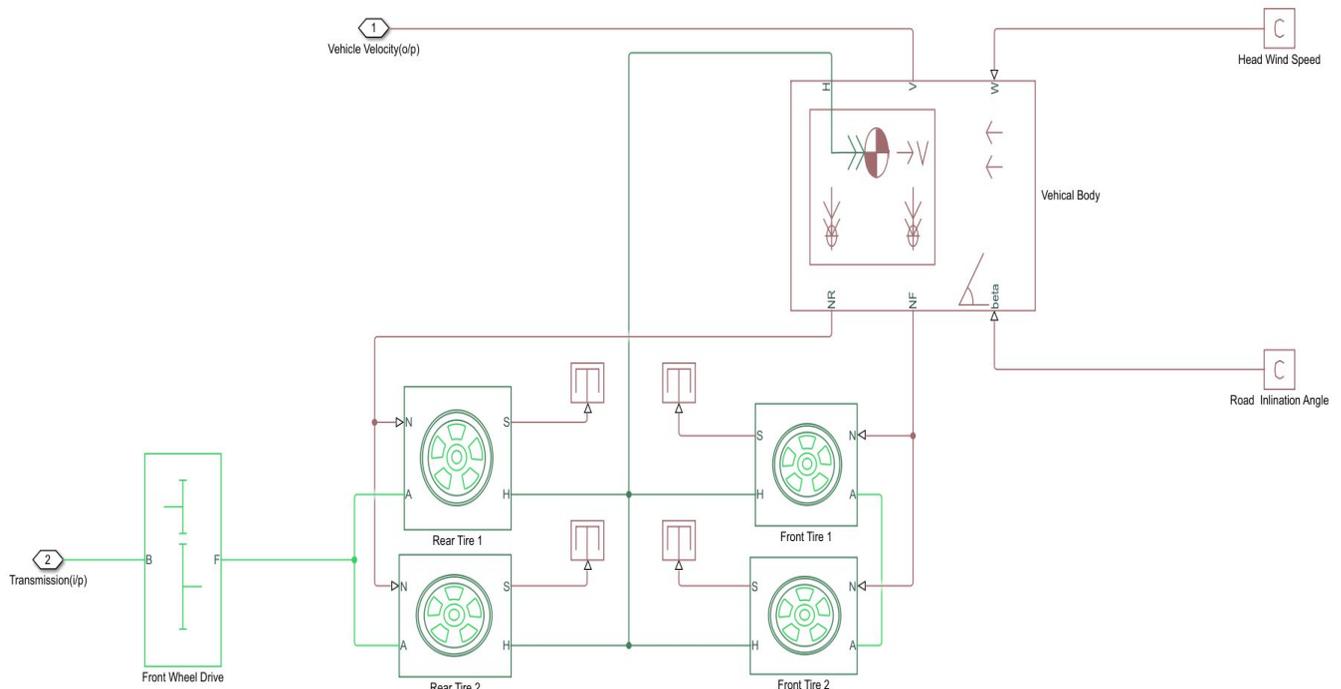


Fig 6.1: Simulation Circuit of Transmission System

6.2.1 Description on circuit of Transmission System:

Here we created a transmission system, which consists of four tires, a physical vehicle body, a simple gear box. The entire system is connected as shown in the Fig: 6.1. Here we created a rear wheel drive i.e., the motor is connected to the axels of the rear two tires through simple gear. This is entirely connected to the vehicle body. The vehicle body produces the velocity as the output of the system, which is further used for the calculations of the distance travelled. We can also vary the angle of the inclination of road, on which the system is being moved and the head wind opposing the speed of the vehicle body. Even the values of the rolling resistance can also be adjusted in the tire block. The blocks used in this system are the blocks in the MATLAB Software.

6.3 Simulink Circuit of Control System:

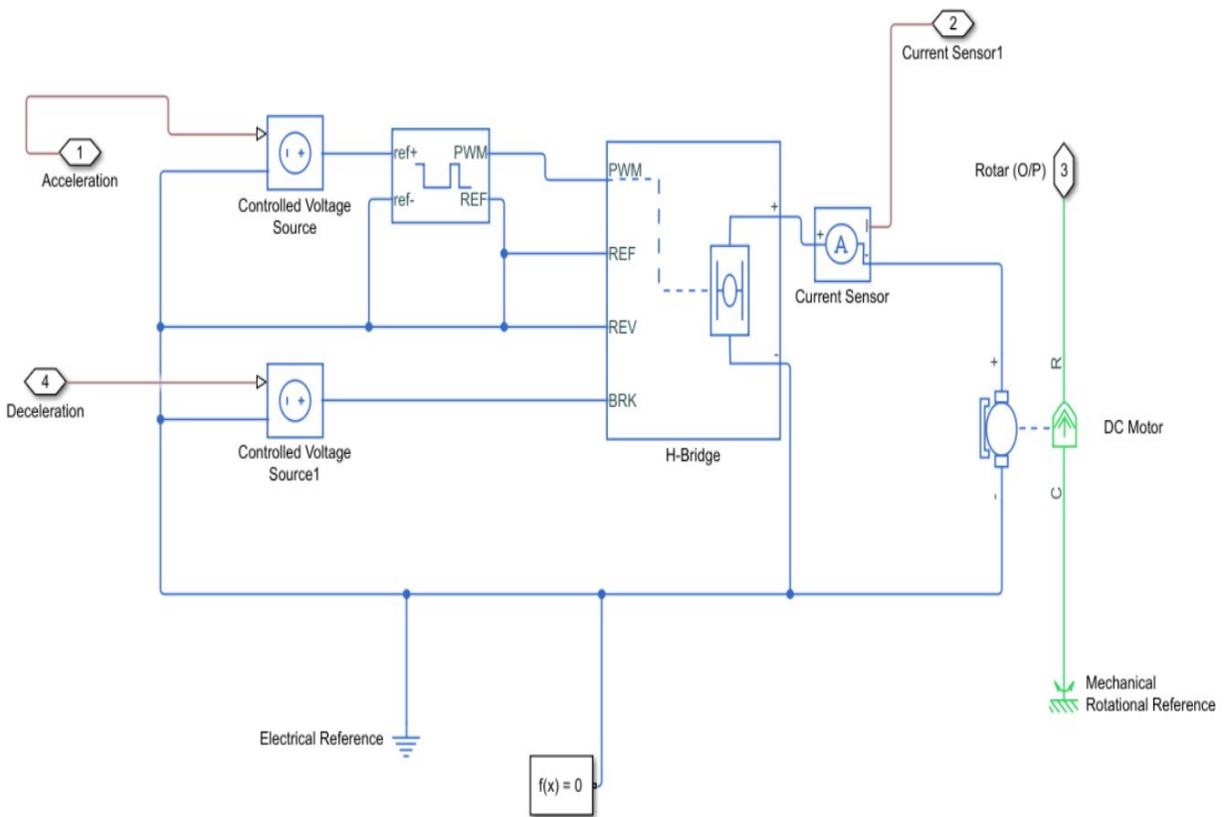


Fig 6.2: Simulation Circuit of Control System

6.3.1 Description on circuit of Control System:

As shown in the Fig: 6.2, we used a H-Bridge convertor which is used for the purpose of the withdrawing the power from the battery, which is further transferred to the motor to drive the entire body. The supply for the H-Bridge is from the PWM (Pulse Width Modulation) Block, i.e., the input to simulate the H-Bridge model is PWM Signals. The signals generated are sent to the H-Bridge model through PWM Input port. The output port of the H-Bridge is based on the pulses sent in to it. The pulses are generated based in the information from the Acceleration command of the Drive Controller. At the time of breaking the motor is forced to supply the current to the battery by the means of the H-Bridge. This effect of motor generating the current is known as DYNAMO effect. In this period of effect, the motor acts as a Generator for short term in order to produce the currents.

These currents generated by dynamo effect are further sent to the Battery. The Controlled Voltage Sources are used to convert input signal into an equivalent voltage source. The generated voltage is driven by the input signal of the block. You can initialize the Controlled Voltage Source block with a specific AC or DC voltage. Similarly, the Current Sensor is used to sense the amount of currents being drawn and sent from/to the battery.

6.4 Simulink Circuit of SOC:

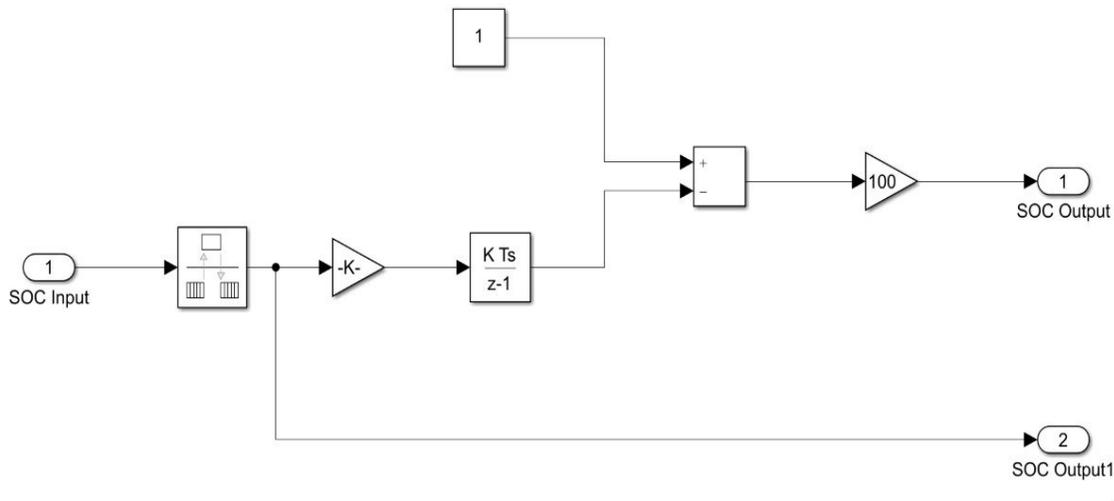


Fig 6.3: Simulation Circuit of SOC

6.6 Results:

The following are the simulation results regarding Speed, Distance, SOC, Currents.

Speed:

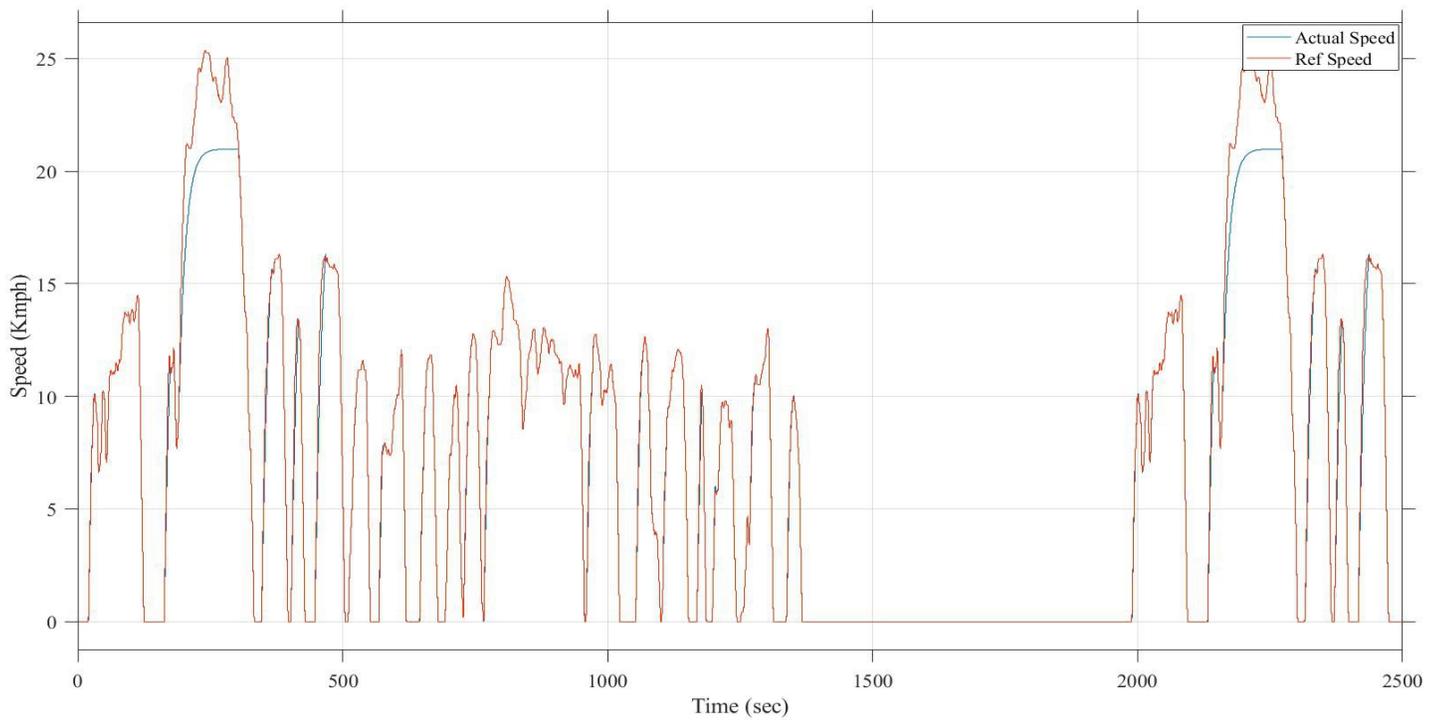


Fig 6.5: Result on Speed of Vehicle

Discussion on result of Speed:

The Actual speed of the vehicle (Blue) versus the Actual speed of the Drive cycle (Violet). As we can see the speeds of actual path and obtained body are of similar and are overlapping each other at almost of the time.

Distance:

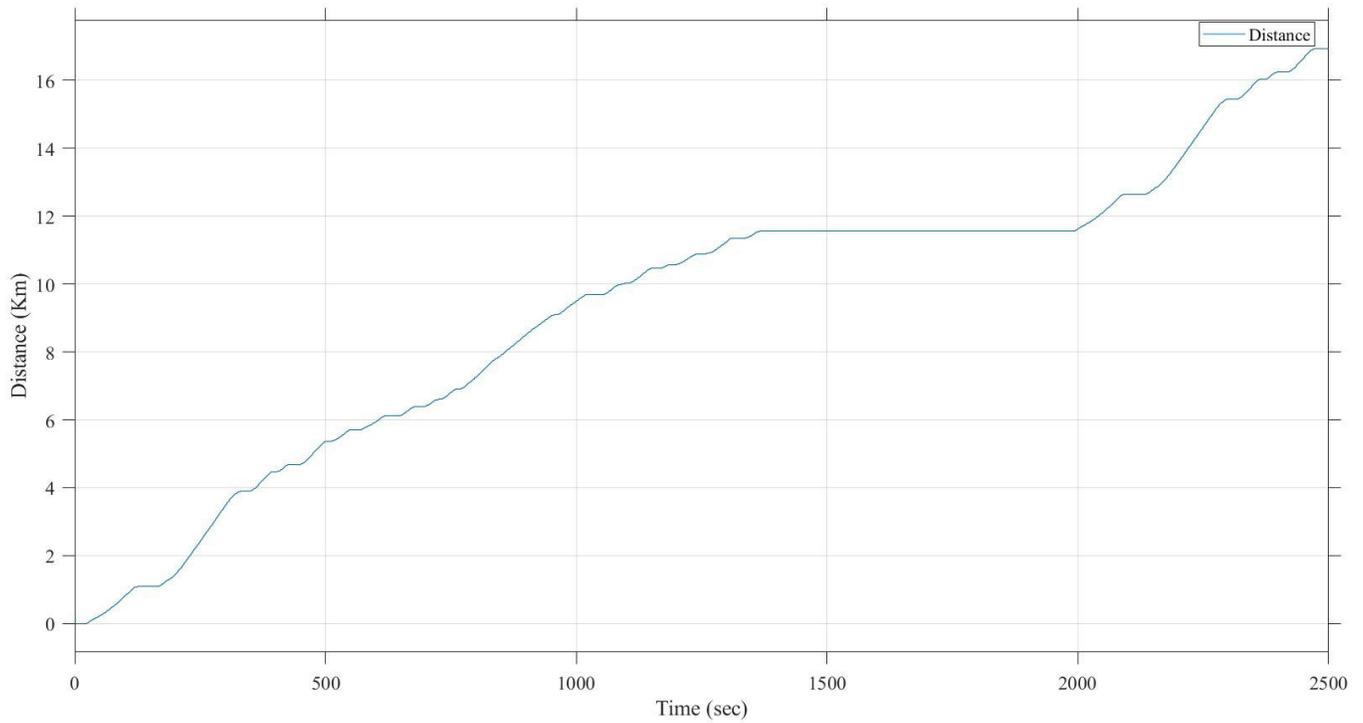


Fig 6.6: Result on Distance of Vehicle Travelled

Discussion on result of Distance:

The total distance travelled by the Drive Cycle Path (FTP75) for a battery charge of 80Ah is of around 16.5 Kms. The distance travelled is similar to that of the path traced out.

SOC:

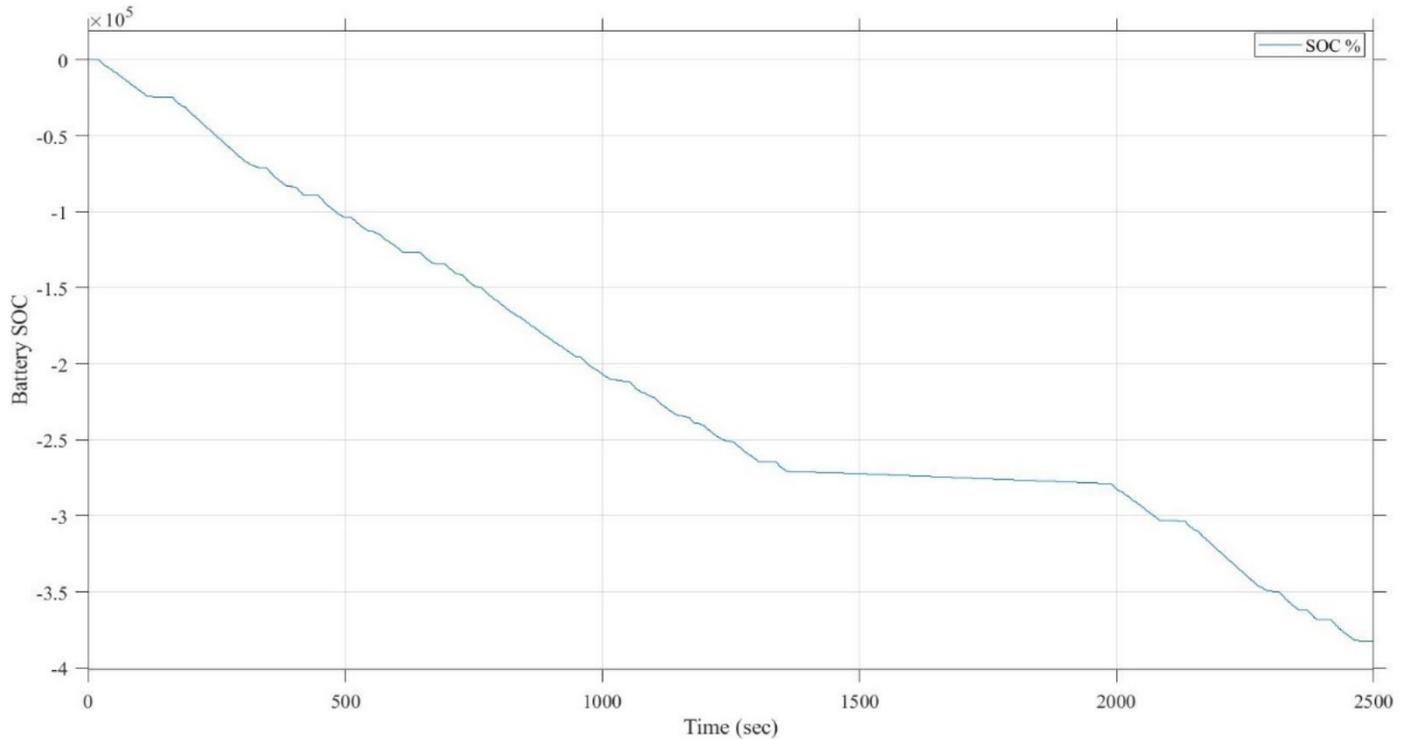


Fig 6.7: Result on Battery State of Charge

Discussion on result of SOC:

As we can see the charge left over in the battery after a distance travelled of 16.5 Kms is approximately 15%. As we can also observe small bulges over the line of the decrement, which are due to the cause of the power supply to the battery due to the braking effect.

Currents:

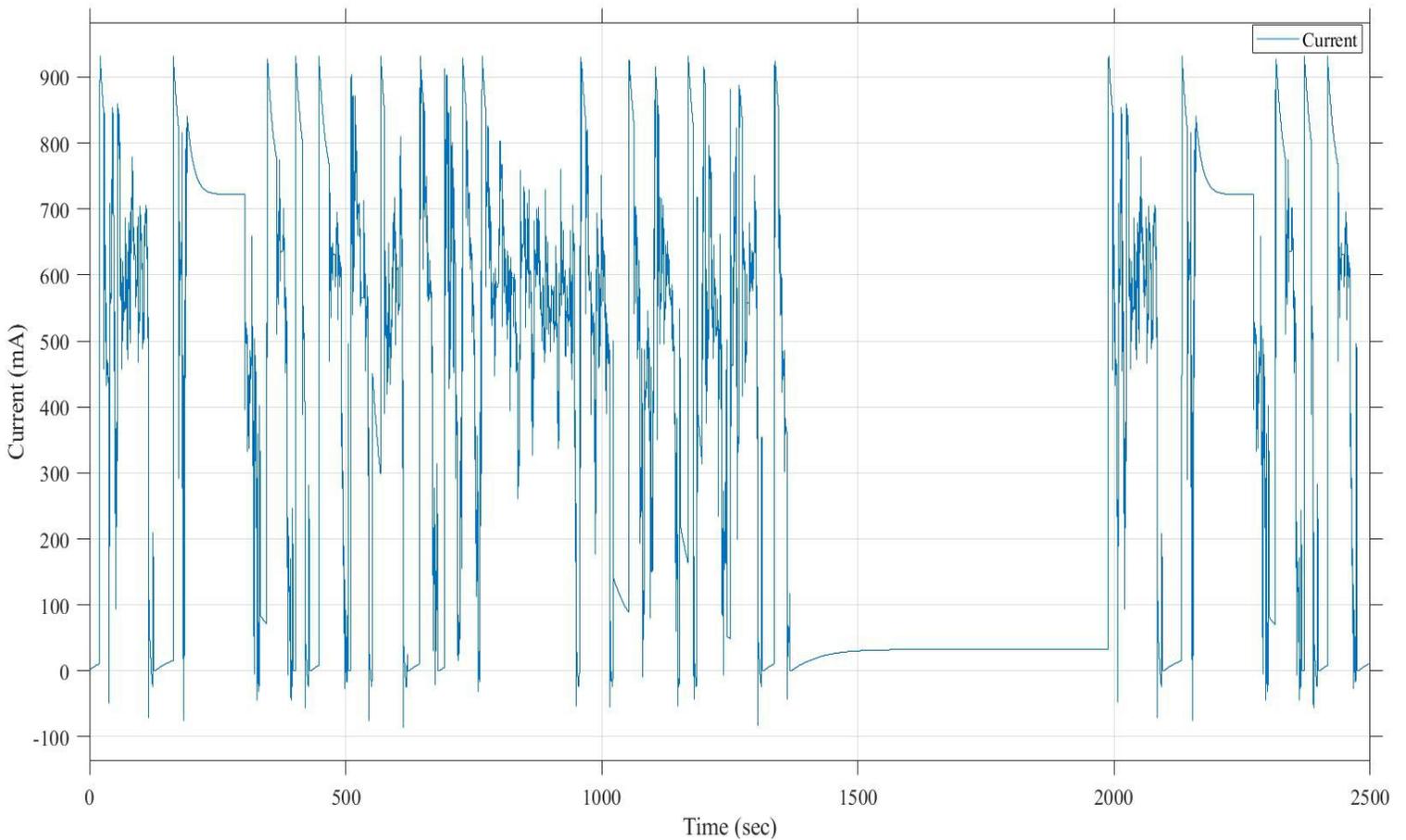


Fig 6.8: Result on Currents drawn by the Motor

6.7 summary:

In this Chapter we have discussed about simulation circuit Blocks of all parts and also give detailed information about the Simulink circuits and also discussed about Results on Speed, Current, Distance travelled and State of charge.

CHAPTER-7

CONCLUSION

7.1 Conclusion:

In this study, Battery Electrical Vehicle system with Field oriented motor control and regenerative braking control is modelled and simulated in Simulink environment. Electric vehicles are necessary in the shift away from combustion engine vehicles in order to reduce the transport sectors greenhouse gas emissions. Physical modeling approach has been used for vehicle modeling to improve the modeling efficiency. Regenerative braking control is also been employed at the time of deceleration so that the kinetic energy is not wasted as heat some amount of it can be recovered and used for charging the battery, which can increase the Electric vehicle range. Battery charging at the time of regenerative braking and acceleration time of the vehicle from 0 – 60 Km/h is observed from the simulation model output. Simulation model can be further improved by deploying the mentioned further improvements.

7.2 Future Works:

- Temperature profile of the batteries in an Electric vehicle can be analysed depending on different drive profiles.
- Waste heat recovery system can be employed in Battery driven vehicles which can improve the overall efficiency and State of charge of battery.
- Lateral dynamics of the vehicle can be included which can show the stability behaviour of the vehicle during over steering and under steering sort of conditions.
- Range prediction can be employed in the simulation model
- Soft switching techniques like Zero Voltage Switching (ZVS) and Zero Current Switching (ZCS) can be employed in the converter control so that there will be a significant reduction in switching losses.

REFERENCES

1. A. A. Abulifa; R. K. Raja Ahmad; "Modelling and simulation of battery electric vehicle by using MATLAB - Simulink" Conference paper, 2017.
2. Sai Krishna vempalli; J. Ram Prabhakar; "Electric vehicle Designing Modelling and Simulation" Conference for convergence in Technology, 2018.
3. Rahul, K. J. Ram Prabhakar "Comparative study on modelling and estimation of State of Charge in battery." International Conference On, pp. 1610-1615. IEEE, 2017.
4. Meradji, M. Cecati, C., Wang, G., & Xu, D "Dynamic modelling and optimal control for hybrid electric vehicle drivetrain "International Conference on Industrial Technology, 2016.
5. Rahul, K. J. Ram Prabhakar "Comparative study on modelling and estimation of State of Charge in battery." International Conference On, pp. 1610-1615. IEEE, 2017.
6. Mishra, Prasun, Suman Saha, and H. P. Ikkurti. "Selection of propulsion motor and suitable gear ratio for driving electric vehicle on Indian city roads." In Energy Efficient Technologies for Sustainability (ICEETS), 2013 IEEE International Conference on, pp. 692-698
7. Nugraha, Febri Arwan, Agus Purwadi, Yanuarsyah Haroen, and Nana Heryana. "The calculation of electric motor and Lithium battery capacity on Cikal Cakrawala ITB electric car." In Power Engineering and Renewable Energy (ICPERE), IEEE International Conference.
8. Venkatesh, B.; Guan, L. Optimal scheduling for charging and discharging of electric vehicles. IEEE Trans. Smart Grid **2012**, 3, 1095–1105.
9. Boynuegri, A.; Uzunoglu, M.; Erdinc, O.; Gokalp, E. A new perspective in grid connection of electric vehicles: Di_ erent operating modes for elimination of energy quality problems. Appl. Energy **2014**, 132, 435–451.
10. Jadhav AR. "Drive Cycle Analysis for Electric Vehicle using MATLAB", International Journal of Engineering Science, 2017 July.
11. L. Buccolini, A. Ricci, C. Scavongelli, G. DeMaso-Gentile, S. Orcioni, and M. Conti, "Battery Management System (BMS) simulation environment for electric vehicles," in 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), 2016.
12. Zhou Bing, Jiang Qinghua, Yang Yi, & Wang Jisheng. (2010). Analysis of energy consumption and powertrain parameters optimization of BEV based on running cycle. In 2010

IEEE 11th International Conference on Computer-Aided Industrial Design & Conceptual Design 1 (pp. 1284–1290). IEEE.

13. T. A. T., Hassan, M. K., & A. Aziz, W. (2015). Mathematical Modelling and Simulation of an Electric Vehicle. *Journal of Mechanical Engineering and Sciences*. Mohd,
14. NPTEL Web lectures on “Introduction to Hybrid and Electric Vehicles”.
15. Singh AK, Dalal A, Kumar P. “Analysis of induction motor for electric vehicle application based on drive cycle analysis”. In *Power Electronics, Drives and Energy Systems (PEDES)*, IEEE International Conference on 2014.