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MASTER THESIS

Design and Modeling of Self-power Generating Electric Vehicle

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By

Biniam Zemedkun

Master Proposal in Partial Fulfillment of the Requirement for Degree of Masters of Science in Mechanical Engineering (Motor Vehicle Engineering Stream)

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Design and Modeling of Self-power Generating Electric Vehicle October 2021

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A Thesis in Partial Fulfillment of the Requirements for the Degree of Master of Science in Motor Vehicle Engineering

Presented to College of Engineering
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Advised by: Dr. Anand S.N

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October 2021

DECLARATION

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Abstract

Because of the role of emissions to global warming, complex petrol engine design, and also body controls, vehicle technology is undergoing a revolution in the design of its electrical mechanical system. Improved battery technology, a sustainable power source for the battery, and styling methods of production and self-charging method are three key identifiable categories of work in the creation of the new electric car. The development of vehicles has been extremely rapid in recent years, in all aspects, from body design to power usage, but beyond that, the development in energy consumption is not like its impact. And nowadays, car technology has progressed to totally in electrification and vehicle autonomous. The aim of this work is to design and develop medium duty vehicle, also referred to as an electric drive vehicle, uses one electric motors or traction motors for propulsion and vehicles use self-generating power to drive the vehicle from power sources. However, the current electric vehicle raise a question in effectiveness of an electric vehicle when traveling 60-100 miles on a single charge: it is still difficult to travel great distances by electric vehicle from a practical standpoint. Furthermore, the recharging time of an electric car is substantially longer, and finding a charging station is sometimes difficult. So to overcome this problem up to certain extent this research offers self-power generating electric vehicle mechanism. In this self-powered system the author has applied the concept of energy cycle from the electrical to mechanical and back to electrical. The system uses a battery charge by using alternator. To do this the alternator which is used for charging battery's is assemble in propeller shaft. Here the propeller shaft is used as rotor and rotates freely, the stator which encloses the shaft and/or rotor is hanged up in correct position in the assembly of the chassis of the vehicle body in such manner that this eco-friendly technology is developed.

Keywords: *self-power generating, automobile, battery, efficiency, eco-friendly, alternator, electric vehicle.*

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Abbreviations

AC..Alternate Current

BEVs..Battery Electric Vehicles

BMS...Battery Management System

DC..Direct Current

EM..Electric Motor

EMF...Electro Motive Force

EVs..Electric vehicles

ESS..Energy Storing System

FCEVs..Fuel Cell Electric Vehicles

FOC...Field Oriented Control

GHG...Greenhouse Gas

GS..Gigabit Switch

GVW..Gross vehicle weight

HEVs..Hybrid Electric Vehicles

HP..Horse Power

HS..Harmonized System

ICE...Internal Combustion Engines

ICEVs...Internal Combustion Engine Vehicles

LHDVs...Light Duty Vehicle

MHDEV...Medium and Heavy Duty Electric Vehicle

PMBLDC...Permanent Magnet Brushless DC Motor

RPM...Revolution Per Minute

PHEV...Plug-in Hybrid Electric Vehicle

PWM..Pulse Width Modulated

SOC..State of Charge

Acronyms

R_r .... Rolling resistance (N)
C_r .... Coefficient of rolling resistance
m .... Vehicle gross weight (kg)
a .... Acceleration due to gravity (m/s^2)
ρ .... Density of the air medium (kg/m^3)
v .... Velocity of vehicle (m/s)
c_d .... Drag coefficient of air resistance
A_f .... Frontal area of the vehicle (m^2)
V .... DC voltage (v)
L .... Inductance of winding (H)
R .... Resistance of the winding (Ω)
T_e .... Torpue of BLDM (N.m)
P_{out} .... Output power (watt)
P_{in} .... In put power (watt)
T .... Time required to cover the distance(s)
D .... Range or Distance covered (m)
Q .... Charge Capacity (kwh)
C_c .... Cell capacity (v)
V_c .... Cell Voltage (v)
P_c .... Cell in parallel combination
S_c .... Cell in parallel combination
C_t .... Total number of cell
I .... Current (A)
C_n .... Maximum capacity that the battery can hold
P_{ch} .... Total charge power (v)
E_{cap} .... Total capacity of the battery (kwh)
K_d .... Distribution factor
P .... Number of poles
f .... frequency of electromotive force (Hz)
N_s .... Speed of shaft (rpm)

E_{ph} .... Induced emf per phase (H)

Z_{Ph} .... Number of conductors/phase in stator

T_{Ph} .... Number of turns/phase

E .... Effective voltage (v)

E_L .... Line voltage (v)

I_L .... Line current (A)

P_{total} .... Total power (watt)

E_{nl} .... No load voltage (v)

E_{fl} .... Full load voltage (v)

Greek Letters

E_{fl} .... Full load voltage

λ .... Rotational inertia coefficient

ω .... Rotational Speed

Ω .... ohms

π .... pi

CHAPTER 1

1.1 Introduction

The health of the people's economic progress is dependent on a well-functioning transportation system. The current transportation system, on the other hand, is heavily reliant on internal combustion engines (ICEs) fueled by petroleum, with new products relying on electric energy as the next challenge and opportunity for automakers. This makes the country vulnerable to the whims of the global oil market.[1]. However, the transportation sector has become the economy's major producer of greenhouse gas (GHG) emissions.[2]. The figure 1.1 shown below is model for conventional vehicle which fuel based its coverage in ethiopia is more than 99%.

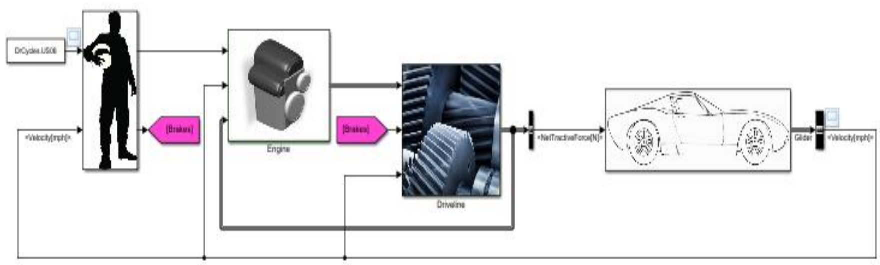

Figure 1.1: Conventional vehicle model

Because of the impending shortage of crude oil and the pressing need to reduce GHG emissions, a growing number of national talents and resources are focusing on developing a sustainable transportation system that can address the climate change challenge while also reducing reliance on oil and electricity.[3]. Figure 1.2 show electrification of goods transporting vehicles is seen as one of many creative technologies that might considerably reduce oil and electrical energy dependence, improve vehicle efficiency, and cut carbon emissions.

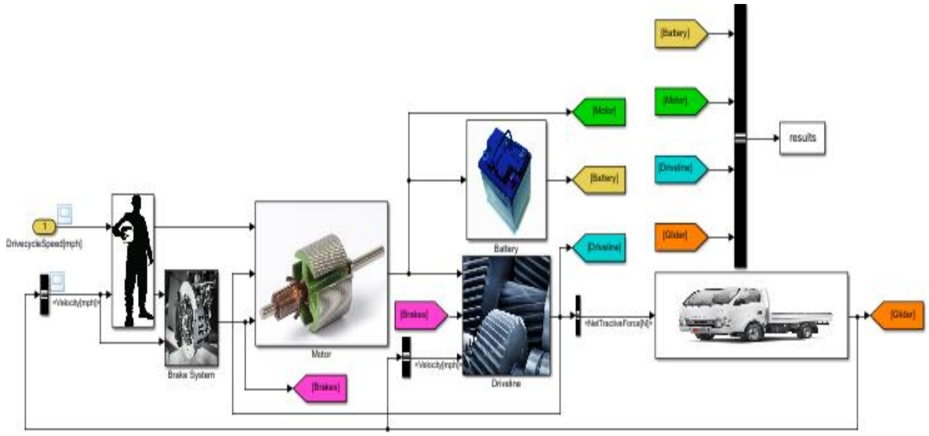

Figure 1. 2: Electrification of goods transporting vehicle Matlab model.

1.2 Background of Electric Vehicle

The electrification and automation megatrends are providing new problems for automakers, resulting in new needs for future vehicles and paving the way for new, as yet uncharted mobility systems. Autonomous driving, for example, will improve safety, availability, and efficiency while powertrain electrification offers a cleaner future. These tendencies, on the other hand, produce new boundary constraints and cost structures during vehicle development. When compared to internal combustion engine vehicles (ICEVs), the traction battery increases both the vehicle's weight and purchase price in the case of BEVs [4].

The electric vehicle was first developed in the 1830s by a number of inventors including Thomas Davenport and Robert Anderson. These early electric vehicles ran on non-rechargeable batteries and far outsold gas cars for decades. However, cars were still a curiosity for the rich. Henry Ford chose gas power over electricity and steam because gas cars could travel much further between refueling. Furthermore, electric cars were vulnerable to breaking down, and mechanics were few and far between. With the success of the assembly-line-produced Model T, America's need for gasoline soared as well. Congress sought to reduce air pollution and vulnerability to growing oil prices in the 1960s and 1970s, which sparked renewed interest in electric vehicles. In the late 1990s and early 2000s, a mix of governmental and private investment fueled the start of mass production of electric vehicles.[5]

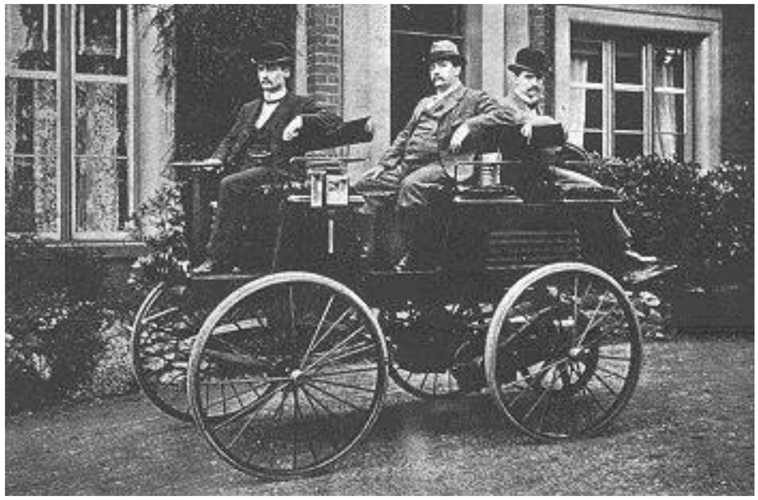

Figure 1.3: Robert Anderson's Electric Vehicle, 1832[6]

Apart from the many-fold growth in vehicle numbers and travel volumes, the worldwide road transport system exhibited surprisingly little change from 50 years earlier at the start of the twenty-first century. In 2000, there were 835 million cars with four or more wheels, with 610 million of these being passenger vehicles. Furthermore, there were an estimated 130 million motorcycles, mostly in Asia. In recent years, around 55 million new cars and other light passenger vehicles, as well as 2.2 million large commercial vehicles, have been produced annually (trucks and buses)[7].

In the late 1800s, electric vehicles (EVs) were first introduced. They were quite popular, and a large number of electric vehicles were sold until around 1918. With the improvement of gasoline engines and their inexpensive cost, as well as the discovery of electric starters for ICEs, interest in EVs has dwindled dramatically. In the meantime, other firms continued to experiment with various types of propulsion motors, energy storage systems, and power conversion technologies in order to enhance EV technology research and development. The propulsion system, which provides the tractive effort to propel a vehicle, is a vital subsystem in an EV. In an electric vehicle, the propulsion system consists of an energy storage system, a power converter, and a propulsion motor with associated controllers. The battery is a common energy storage technology, and its charge is an important aspect of the electric vehicle system.[9]. Vehicles that run on electricity Because of their positive impact on lowering negative environmental consequences and technological advancements that allow them to compete with traditional fuel-powered vehicles, electric vehicles are regarded the most promising technology in the world. However, there are still a number of concerns with electric vehicles that need to be addressed, the majority of which are related to the vehicle's battery. The battery's capacity poses a barrier to the driving range, raising EV prices and, in certain circumstances, requiring a long time to recharge. As a result, many patents attempt to explain solutions to these problems, one of which is the self-charging electric cars patent. A high-voltage battery with a voltage greater than 200 volts was used in electric vehicles. The battery comes in a variety of kinds, including lithium ion, which is the one employed in this study. The three primary types of electric motors used in electric cars are induction motors, permanent magnetic synchronous motors, and switch reluctance motors. The motor will be driven by power electronics (AC motor drive), and regenerative braking will occur when the motor is used as a generator. In comparison to other motors, the induction motor, which is easy to regulate using the field oriented control (FOC) method, switching reluctance motor has a simple structure, low cost, low efficiency, and small size. Permanent magnetic synchronous motors can operate at a wide range of speeds without the use of a gearbox, and they have excellent efficiency and torque at low speeds, making them suitable for use in in-wheel motor systems [10]. I need to use a direct current – direct current (DC-DC) converter boost for this project. It has a wide range of applications, including renewable energy and electric cars. When comparing the Boost Converter to the Buck and Buck-Boost Converter, the Boost Converter is more difficult to implement since it has a zero root in the right half of the s-plane and is a non-minimum phase system. [11, 12].

1.3 Problem Statement

The current electric vehicle have some drawbacks, To provide adequate electricity to EV's, a considerable amount of charging stations might need to be built, let alone power plants to support them and even after this all, when the owner pull the car into a gas station to recharge, an electric vehicle takes much longer time to recharge. Many electric cars can be full in around four hours, but some can take nearly a day to fully recharge and even in such situation, when you take off on a road trip or decide to visit family in a rural or suburban area, it may be harder to find a charging station. And for some time Electric Vehicles have been proposed as good transportation in the future but they have not gained overall acceptance and the technology has remained as one for enthusiasts. Reasons for this are many but a prime one is likely that the technology has always been expensive in compared with conventional vehicles that mean sticker price of electric vehicle too high. Furthermore, the maintenance costs of an electric powertrain are around one-third of the costs of maintaining a combustion engine powertrain. These costs will reduce even further when EVs become a more common means of transport. Moreover, the energy use of an electric motor is on average less than a third of the energy needed with a combustion engine.

1.4 Objective

1.4.1 General Objective

The general objective of this research is to design and modeling of self-power generating electric vehicle.

1.4.2 Specific Objectives

- ✓ To design alternator with respect to the propeller shaft speed, synchronize the speed of DC motor with electrical charge output frequency and geometrically optimized;
- ✓ To detail calculation on electrical power requirement, charge output from the alternator and battery capacity requirement; or/and power balance between demand and supply;
- ✓ To Matlab model for optimum design electric vehicle and analysis the result;
- ✓ To Matlab model the overall configuration of electric vehicle based on the different input and analysis the result;
- ✓ To model speed control model BLDC motor using hall sensor and analysis the result;
- ✓ To model battery in both case i.e in charging and discharging and analysis the result;
- ✓ To model alternator and check the stability of different parameter; and

1.5 Significance of the Thesis

One of the primary reasons for the introduction of self-power generating electric vehicle is to save electric energy and reduce the running cost of the vehicle in addition to this concern of greenhouse gas emissions, their contribution to global warming therefore purpose of creating self-power generating cars that reduced or eliminated exhaust emissions which is or was the combat issue of the world and/ or to fulfill zero-emission vehicle action plan. As we know, today world is so fast this is possible only because of fast transportation, but in this world current electric cars have the following drawbacks recharging the battery takes time, they are usually more expensive than gas-powered cars, and it can sometimes be difficult to find a charging station, these is the starting point for my work.

A self-charging car is a car that can drive itself using electric power alone, but can't be plugged in to charge this produce effect on economic condition of our country's. And if electric power is become minimum that time our world transportation very slowly or may come to idle. And regarding to fuel vehicles, when the storage of fuel is imitated that means when the storage of fuel is totally finish that time transportation is totally stop. There for today's need is self-power generating electrical vehicle that generate owner power and work on self-power without effect on working of operation and this is not having any type of external energy it is free from pollution. And finally the automotive industry in particular, the researcher, vehicle owners, drivers, and the country when the outcome from the thesis becomes evaluated and implemented. The following are the extent to which the proposed thesis work is important.

- ❖ Saving cost of fuel and electric energy coast.
- ❖ Saving currency invested for import of vehicle.

Therefore EVs have the advantages of being environmentally friendly, 2) based on the notion of renewable, cost effective, and energy efficient, but they also have the disadvantages of 1) battery recharging, 2) charging time, 3) driving range, and 4) battery pack health. The author examine and contrast the cost structures of BEVs and ICEVs. Which compares the expenses of a tiny ICEV with those of a comparable BEV with a 50 kWh battery, battery costs can account for up to one-third of total vehicle costs? In 2020, an ICEV is still much less expensive than a BEV, but by 2030, declining battery prices will narrow the price gap to just 9%.[4]. These developments will contribute to the creation of a sustainable society by promoting the use of EVs and reducing CO2 emissions. And basically for the country like Ethiopia reduce oil dependency.

1.6 Scope of the Thesis

The drawback in electric vehicle and internal combustion is the motivation behind this work, and needs to dedicate for light duty vehicle including automobiles. These studies incorporate numerical calculation, and modeling and simulation. This work is applicable for light duty vehicle that include automobiles. Therefore, based on the available time, the thesis work is limited to numerical calculation, modeling and simulation.

1.7 Organization of the Thesis

The paper is organized into five chapters. Each chapter classified according to the approach used to articulate the paper and to solve the problem raised.

Chapter one- It deals about introductory parts of the paper. It includes background, objective, statement of the problem, significance of the project and organization of the study are well explained. *Chapter two* - Focused on a literature review surrounding the subject of this thesis work. The models of self-charging electric vehicle, parts of electric vehicle and fundamental of vehicle dynamics are explained. The developments on electric vehicle with self-charging system are mentioned. Finally, the research gaps are identified. *Chapter three*- Describe the Materials and methods used in this thesis work. Data analysis and analysis method, design procedure and flow chart of work necessary for the thesis are elaborated and design calculation of the research are discuses. On the other hand, *Chapter four* – Modeling, deals about result, and discussion. *Chapter five* - deals with summery of this project recommendation and conclusion.

CHAPTER 2

Literature Review

2.1 Introduction

The following section reviews different research surrounding the subject of this thesis, the design of self-power generating vehicle. The increased global focus on energy saving and grid technology are discussed, specifically in the area of automobile sector. Different problems of electric vehicle and internal combustion engine are explained. Developments of vehicle technology are discussed; with review of different article in vehicle technologies.

2.2 EVs Types

EVs can run entirely on electricity or in conjunction with an internal combustion engine. The most basic type of EV is one that uses solely batteries as an energy source, however there are others that can use various energy sources. These are known as hybrid electric vehicles (HEVs). Technical Committee 69 (Electric Road Cars) of the International Electro technical Commission proposed that vehicles with two or more types of energy sources, storage, or converters can be classified as HEVs as long as at least one of them provides electrical energy. [15]. This specification allows for a wide range of HEV pairings, including ICE and battery, battery and flywheel, battery and capacitor, battery and fuel cell, and so on. As a result, both the general public and experts began referring to vehicles with an ICE and an electric motor as HEVs, those with a battery and capacitor as ultra-capacitor-assisted EVs, and those with a battery and fuel cell as FCEVs. [16]. these terminologies have become widely accepted and according to this norm, EVs can be categorized as follows:

2.2.1 Battery Electric Vehicle (BEV)

BEVs are electric vehicles (EVs) that just have batteries and do not have an internal combustion engine (ICE) to give power to the drivetrain. BEVs must rely only on the energy stored in their battery packs, hence their range is directly proportional to their battery capacity. They can often travel 100–250 kilometers on a single charge [17]. These ranges are determined by factors such as driving style and conditions, vehicle configurations, road conditions, climate, battery type, and age. When the battery pack is discharged, charging it takes a long time compared to refueling a standard ICE car. It can take up to 36 hours to fully recharge the batteries.[18]

2.2.2 Hybrid Electric Vehicle (HEV)

Electricity and gasoline are the two forms of energy storage units in a hybrid electric vehicle (HEV). Electricity indicates that the energy is stored in a battery (occasionally with the help of ultracaps) and that the traction motor is an electromotor (from now on referred to as motor). Fuel entails the use of a tank, as well as the use of an Internal Combustion Engine (ICE, from now on referred to as engine) to generate mechanical power or the use of a fuel cell to convert fuel to electrical energy. [19]. the energy flows in a basic HEV are depicted in Figure 2.1. ICE uses the vehicle and the motor as a generator to charge the battery while traveling. When the vehicle comes to a complete stop, the power flow is interrupted. To achieve optimal fuel efficiency, the one shown above divides power between the ICE and the electric motor (EM) by taking into account vehicle speed, driver input, battery state of charge (SOC), and motor speed.[20]

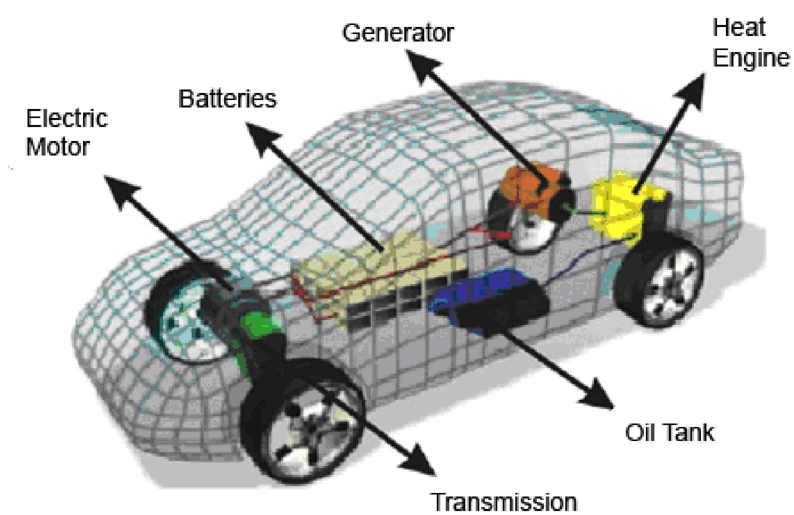

Figure 2. 1: Hybrid electric vehicle [20].

This hybrid vehicle system has different configuration

Series hybrid: - Instead of driving the wheels directly, the combustion engine powers an electric generator (typically a three-phase alternator + rectifier) in a series hybrid system. [21].

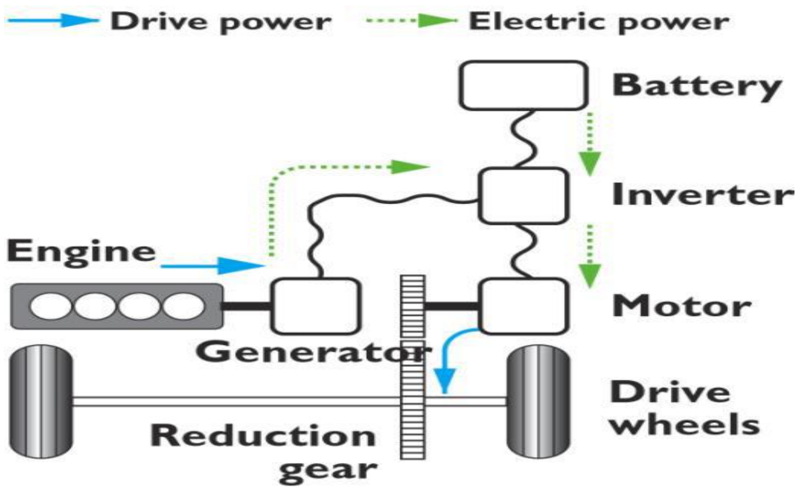

Figure 2. 2: Series hybrid configuration [21].

- **Parallel hybrid :-**Parallel hybrid systems have both an internal combustion engine (ICE) and an electric motor in parallel connected to a mechanical transmission.

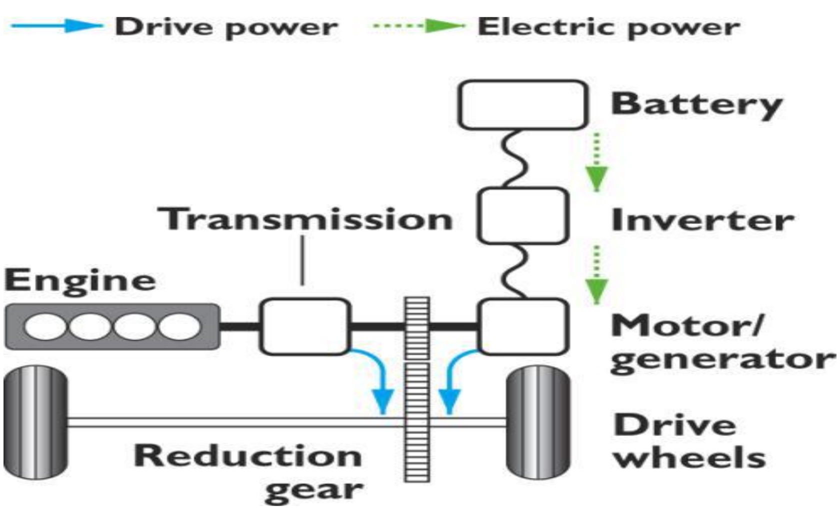

Figure 2.3: Parallel hybrid configuration [21].

- **Combined hybrid**

Both series and parallel hybrid systems are present in combined hybrid systems. There are two mechanical and electrical connections between the engine and the drive axle. But the main principle behind the combined system is the decoupling of the power supplied by the engine from the power demanded by the driver. [21]

2.2.3 Plug-in Hybrid Electric Vehicle (PHEV)

PHEVs start in 'all electric' mode, run on electricity, and then call on the ICE for a boost or to charge up the battery pack when the batteries are low on charge. The ICE is employed to expand the range in this case. PHEVs have the ability to charge their batteries directly from the grid. [22]

2.2.4 Fuel Cell Electric Vehicle (FCEV)

FCEVs (Fuel Cell Electric Vehicles) are a type of electric vehicle that runs on hydrogen (FCV). Fuel cells, which produce electricity through chemical reactions, are at the heart of such vehicles. Fuel cell technologies for MHDVs and passenger vehicles are still being developed. Because hydrogen is the preferred fuel for this reaction in FCVs, they are often referred to as "hydrogen fuel cell vehicles." The fuel cells generate electricity, which is used to power an electric motor that powers the wheels. Excess energy is stored in energy storage devices such as batteries and super capacitors. [23,24]. Fuel cells, which are most commonly powered by hydrogen, are useful in applications that need zero carbon (CO2) emissions, as well as zero NOx and hydrocarbon pollutants.[25].

2.3 Basic Parts of Electric Vehicle

2.3.1 Electrical Energy Storage

Electrical energy can be stored in a variety of ways, but for newly constructed vehicles, two approaches have emerged as the key solutions: batteries and super capacitors. To compare the two types of energy storage devices, batteries transform chemical energy into electrical energy. Super capacitors, on the other hand, store energy by maintaining an electric voltage across a dielectric. The super capacitor is a type of capacitor that is specifically developed for energy storage and high-power pulse applications. Batteries and super capacitors both have advantages and disadvantages. Super capacitors have a higher specific energy than batteries, while super capacitors have a higher specific power than batteries. As a result, some vehicles feature both of these forms of storage to allow for greater range of operation.[26]

2.3.2 Battery

The primary differentiation between the various EV manufacturers is the batteries. The range of an electric vehicle is determined by the quantity of energy stored in the battery, which is regarded to be a major barrier to EV adoption. Consumers are concerned that an EV with an 80-250 mile range on a single charge may be troublesome for long excursions due to the time it takes to recharge the battery. Manufacturers have spent millions of dollars to increase the availability and efficiency of electric vehicle chargers, and the fastest ones now take less than 15 minutes to recharge a vehicle. However, there aren't many of them; most users must rely on "slow chargers," which can take significantly longer. The fact that most EVs are charged at work or at home is likely due to the long charging times.[27,28]

Figure 2. 4: Alkaline AA battery cell, Tesla lithium-ion battery cell, and Nissan battery modules and pack. [27].

Battery Packs

The final stage of EV battery production is the production of EV battery packs. Manufacturers can put them together by hand or with automated machinery. According to recent estimates, the pack stage of manufacture accounts for around 14% of the total cost of a finished lithium-ion battery pack. EV battery packs are designed for individual car models and assembled near the vehicle assembly site by battery manufacturers. Battery packs, like all other lithium-ion batteries, are classed under tariff-classification subheading 8507.60 in the worldwide Harmonized Commodity Description and Coding System (HS).[27].

2.3.2.1 Types of Battery used in EV

Lead-acid, Nickel-Metal-Hydrate (NiMH), Nickel-Cadmium (NiCd), and Lithium-ion (Li-ion) batteries are among the many types of batteries used in electric vehicles.

A. Lead Acid

In a traditional car, this sort of battery is utilized for starting, ignition, lighting, and other electrical functions. This type of battery was employed in the early days of electric vehicle technology. Although it is reasonably priced, the battery's construction is too hefty and has insufficient range for EV use.

B. *Nickel-Metal-hydrate (NiMH)*

This type of battery is currently one of the two most popular EV batteries. It is commonly employed in hybrid electric vehicles due to its ability to store significantly more energy than lead-acid batteries, as well as its longer life cycle and less weight. In a hybrid electric car, the vehicle's power comes from either an internal combustion engine or electric motors. This battery has a faster self-discharge rate and can offer a burst of power.

C. Nickel-Cadmium (NiCd)

NiCd batteries have a longer life cycle than NiMH batteries because they can withstand more deep discharge cycles. In comparison to lead-acid, it is also lighter in weight. This battery, on the other hand, had a poor relative electrical capacity

D. Lithium Ion (Li-ion)

High capacity and high performance energy storage systems (ESS) have recently accelerated as a result of competitive research and development efforts around the world. The lithium-ion battery, which first appeared in 1991, has a wide range of applications in energy storage systems. In the beginning, it was commonly utilized for portable electronic gadgets. For electric vehicles and huge ESS, the application range is rapidly expanding. The good news about Li-ion is that it is environmentally benign, with practically all battery components being recyclable. Because of all of the positive characteristics, the battery is more expensive than other battery kinds. Despite this, Li-ion batteries are still the chosen choice for most hybrids and battery electric vehicles. The complete electromechanical process of charging and discharging of this battery is governed by equation [29]. Lithium-ion batteries have a five-fold higher energy density than lead-acid batteries, a discharge loss of only 1/4 that of nickel-metal hydride batteries, no memory effect, and a huge number of charge and discharge cycles.[30]. The currently established technology for BEVs is the lithium-ion battery [31]. A lithium-ion battery is made up of interconnected cells that vary in length, breadth, and height, as well as shape (pouch, prismatic, and cylindrical) depending on the manufacturer. Tesla, for example, employs cylindrical cells, while BMW uses prismatic cells and Nissan employs pouch cells [32].

Table 2.1: Lithium-ion battery components, functions, and main materials [33]

Components	**Functions**	**Materials**
Cathode	• Emit lithium-ion to anode during charging • Receive lithium-ion during discharging	lithium metal oxide powder
Anode	• Receive lithium-ion from anode during charging • Emit lithium-ion during discharging	Graphite powder
Electrolyte	• Pass lithium-ions between cathode and anode	Lithium salts and organic Solvents
Separator	• Prevent short circuit between cathode and anode • Pass lithium ions through pores in separator	Micro-porous membranes

Type and performance of the different battery are finalized in the following table.

Table 2. 2: Types and performance of batteries [30, 33].

Accumulator kinds	Operating voltage [V]	Energy density [Wh /kg	Life expectancy [year] (Cycle)	Battery efficiency [%]	Battery Characteristics
Lead accumulator	2.0	20-35	7-10(1500)	65-80	High reliability, low cost
Nickel hydrogen accumulator	1.2	20-70	(500~1500)	~84	Currently, best value and most popular battery for HEVs
Lithium-ion accumulator	2.4-3.8	70-160	≥10(≥3600)	~95	Small size, light weight

2.3.3 Electric Motors

A machine that converts electrical energy into mechanical energy is known as an electric motor. The induction motor is the most widely used type of motor because it combines all of the benefits of electrical energy - such as low cost, ease of supply and distribution, clean handling, and simple controls - with the benefits of simple construction and great versatility in terms of adapting to a wide range of loads and improved efficiencies. The following are the most popular types of electric motors:

a) Direct current motors

The field winding is connected in series to the armature winding in a DC motor. [34]. These motors are relatively pricey, and they require a direct current source or a mechanism to convert conventional alternating current to direct current. They can operate at a wide variety of speeds and are ideal for precise and flexible speed control. The downside is that the motor's speed regulation is poor, and it must be loaded before beginning. It commutates on a regular basis. The time on our planet is limited. There is a lot of electric noise. The characteristic of speed-torque is somewhat flat.[35] As a result, their use is limited to specialized applications where the greater installation and maintenance costs outweigh the benefits.

b) Alternating current motors:

These are the most frequently used motors because electrical power is normally supplied as alternating current.

C) Synchronous motors:

Synchronous motors are three-phase AC motors that run at a constant speed without slipping and are typically used for high outputs (due to their relatively high costs in smaller frame sizes).

Permanent Magnet Brushless DC Motor

The brushless DC (BLDC) motors are the most popular and widely used in control application [34]. Brushless DC Permanent Magnet Researchers are increasingly turning to (PMBLDC) motors because of its high efficiency, quiet operation, compact size, excellent reliability, and low maintenance requirements. These motors are recommended for a variety of applications, although the majority of them necessitate sensor less motor control. Controlling the winding currents in PMBLDC motors necessitates rotor-position sensing. The sensor-less control would require rotor position estimation using voltage and current signals, which are readily available.[36]. A BLDC motor's simple structure, sturdiness, and low cost make it a potential contender for a wide range of general-purpose applications. The BLDC, when paired with a properly controlled converter, provides a driving system with several desirable qualities. When compared to other electric motors, one of the key advantages of BLDC is its improved speed vs torque characteristics.**[**37**].** Single-phase and three-phase motors are both available. A permanent magnet rotor and wire-wound stator poles are used in this motor. The rotor is made of permanent magnets and can be configured in two-pole to eight-pole pairs, with North (N) and South (S) poles alternated.[38]. The stator windings work with the permanent magnets on the rotor to generate a uniform flux density in the air gap [39]. This allows a consistent DC voltage to operate the stator coils (hence the name brushless DC). The rotor position of a BLDC measured using hall effect sensors is critical because it provides information about the windings that are currently electrified and those that will be powered in the future.[38]. Additionally, sensor-less control techniques can be employed to eliminate position sensors, lowering the motor's cost and size. In fact, control methods like back-e.m.f and current sensing can offer enough data to accurately estimate the rotor position and, as a result, drive the motor with synchronous phase currents. The zero crossing point (ZCP), which is the only location that can provide rotor position information at either 00 or 1800 electrical, is perhaps the most prevalent BEMF approach. To match the commutation cases, the zero crossing point procedures are followed by a phase shift of 300 or 900. A sub-optimal phase current derives from any ZCP detection inaccuracy.[40]

When compared to other motors, the BLDC motor has a better power density, higher torque, lower operating and mechanical noise, no electromagnetic interference, and high efficiency. As a result, this motor is the most often used in electric vehicle applications.[41]. Due to the ability to employ electronic inverters instead of brushes, brushless DC motors are more efficient than brushed DC motors. This inverter increases the speed of Brushless DC motors, allowing them to produce more energy.

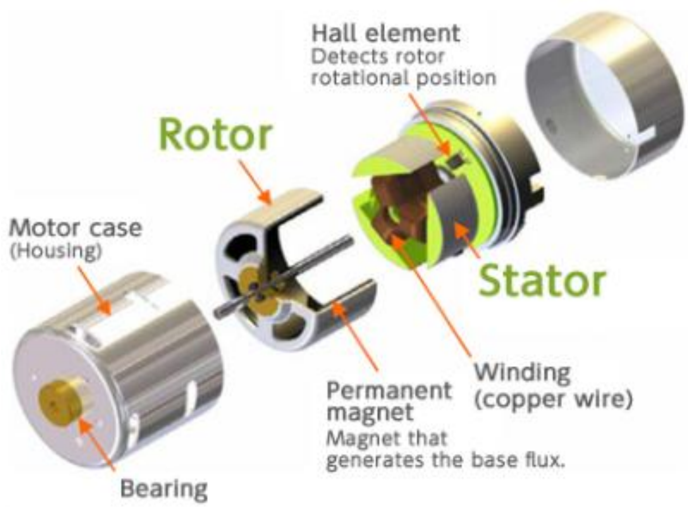

Figure 2. 5: Interior parts of electric motor [41]

The motor model depicts the transition between electrical and mechanical levels. The model comprises of two pins and two output connectors, as shown in Figure 6. The inverter and ground are connected by pins P and N, respectively. The mechanical connector flange is in charge of connecting to the simple gearbox, which produces two outputs: torque flange. tau and motor shaft angle flange a.phi. The variable we is the model's third output, and it contains the electric angular frequency that the motor requires to complete the needed driving cycle.

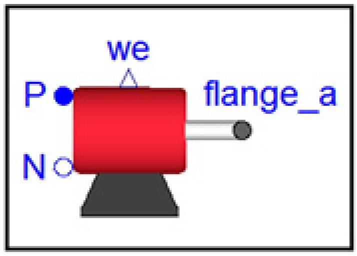

Figure 2. 6: External model of the motor [43].

2.3.4 Motors-Inverters

Inverters are a collection of components that control electrical current to perform useful tasks on board an electric vehicle and convert battery DC power to AC power for use in motors or other power needs. MHDVs require a different set of inverters than LDEVs due to their increased power demand and severe working environs. For the introduction of MHDVs, significant hardening of power electronics is required.[42]. Basically, it converts DC current to AC current based on the balance of input power from the battery and output power provided to the Brushless DC motor.

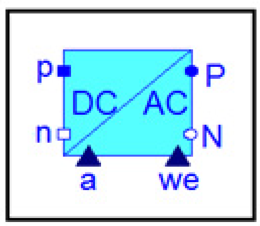

Figure 2. 7: External view of the inverter model.[43]

The model consists of two input pins (p, n), two output pins (P, N), and two connectors, as shown in the diagram above (a, we). The pins n and N are connected to the ground, while pins p and P are responsible for the battery and motor connections, respectively. The control input signal used to adjust the amplitude of the three-phase voltage is represented by connector a, and the electric angular frequency of the motor is represented by connector we.[43]

2.3.5 Gearbox

The gearbox is connected to the electric machine and delivers the torque from the machine to the wheels. This necessitates a torque-to-machine transmission ratio. In the case of BEVs, the electric machine is often equipped with a fixed-ratio gearbox.[44]

2.4 Summery and evaluation of literature

The following are the literature reviews taken from the conclusions of different papers:

Mutlaq Sinhat Al-Otaibi.(Self-Charging System for Electric Vehicles): This paper discussed a method for charging electric vehicles during its trip. So that, the aim of this paper is to know the amount of electrical energy that can be supplied to an electric vehicle by installing this regenerative braking system and adding it to electric vehicles. The speed of the electric vehicle is considered, as well as the energy required by the battery, battery losses, battery recharge, and generator power (loss by adding generator). According to the study, 20 percent of the energy required for an electric vehicle can be saved during the trip if only one generator is used, but this amount decreases when two generators are used, and the reason for this is that using two generators reduces the speed of the electric vehicle. The figure below shows an electric vehicle with tow generators, which results in a reduction in speed.

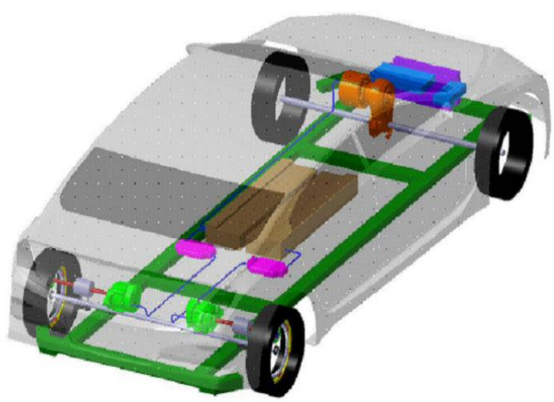

Figure 2. 8: Electric Car with Self-charging System. [45]

The system was simulated using Matlab, and the effects of adding one and two auxiliary synchronous generators to the car, as previously described, on the electric vehicle's performance were measured. The electric vehicle is powered by a permanent magnet synchronous motor (PMSM) and a 3 kW generator, which is coupled to the wheels via a 1:4 gearbox. When adding a generator and two generators, the effect of the invention on the vehicle's speed was investigated. The effect of the invention in the gearbox on the energy consumed from the battery, as well as the effect of additional generators on regenerative generation was also described throughout the trip using the recommended method. According to the research, adding generators will cause the electric car to slow down and its speed to drop.[45]

Shubham U. Tayde.[et al](*Self-Power Generating Electrical Bicycle)***:**This paper explain, The self-power generating electrical bike is simply a bike that generates its own power with the use of some equipment and may be driven without the use of external energy. This type of bike does not require any external energy, such as petrol or battery charging. This is charged internally and has no effect on the operation of the self-powered electric bike. This sort of e-bike is evolving all the time, but it does have some limitations, such as external charging. If the battery discharges while traveling, it causes a problem, implying that it should only be used for short distances. As a result, some changes to the e-design bikes are required. This updated design is inexpensive for the average person in our country to purchase. The motor, chain sprockets, flywheel, housing, and rear wheel make up the power transmission system. However, before we could choose these components, we needed to run some fundamental energy transfer calculations through the system. We concentrated on the system's current requirements as well as a variety of torque-speed relationships. The amount of torque supplied by the various system components determines the system's acceleration on level terrain as well as its capacity to climb hills. Before we could size the batteries, we needed to figure out when the motor would require the maximum electricity and for how long it would do so. These would be at the commencement of a climb (acceleration) and when climbing a grade. The motor and the battery are the two key components that are affected by the following calculations. [13].

S Lubis and **Cholish**, (Design *and generating energy as a car alternator to be an alternative electricity):* Power generation based on solar energy, ocean wave energy, and wind energy, which are still being developed in small enterprises, can be replaced by the power plant. While power plants such as hydroelectric power plants (HEPP), diesel power plants (diesel), gas power plants (power plants), nuclear power plants (NPP), and so on cannot be replaced. Fearing that this energy would be depleted, I gradually reduced it. Has explored a variety of additional natural resource use options, and everything that is conceivable might be used to create electricity. Electric energy distribution in locations where the grid does not reach. Alternative power generation and solar power generation are the most efficient and suitable sources of electrical energy. This is backed by the fact that the state of Indonesia is located near the equator, allowing solar energy to be transformed into electrical energy all year. Push research to try to use the car's alternator instead of a generator at power plant alternatives, based on the description above. This study will reveal how to use and improve the performance of the car's alternator's current power plants. For the reasons stated above, the title of this study was changed to "Design of Alternator Car for Alternative Electrical Energy Generation." The engine AC generator, which is the main driving force, can be a manifold turbine engine, a diesel engine, or a propeller engine, where electricity is produced from an electrical energy conversion process that is commonly used. Because of the reliability fluctuations and load size in power plants with generators, two or more generators are run with continuous duty, reserve, and turns to the generator. [85]

Aniket Mishra, Pratik Kale [et al], (Electricity Generation from Speed Breakers). This paper includes how to utilize the energy which is wasted when the vehicles passes over a speed breaker. When a vehicle passes over it, a lot of energy is released. By using the speed breaker as a power generating unit, we may tap into the energy generated and generate electricity. The technique of electricity generation using speed breakers is explained in this project. Rack and pinion arrangements are used to transmit the vehicle load acting on the speed breaker system. The speed-reciprocating breaker's motion is then converted to rotational motion using a rack and pinion arrangement in which the pinion's axis is linked with the sprocket arrangement. Two sprockets make up the sprocket configuration. One of the sprockets has a wider diameter than the other. The power is transmitted from the larger sprocket to the smaller sprocket via a chain that connects both sprockets. The speed available at the larger sprocket is relatively multiplied at the rotation of the smaller sprocket as the power is transmitted from the larger sprocket to the smaller sprocket. The smaller sprocket's axis is connected to a gear arrangement. Two gears with varying diameters are seen here. The axis of the smaller sprocket is linked to the gear wheel with the greater diameter. As a result, the increased speed at the smaller sprocket wheel is passed on to this larger-diameter gear wheel. The smaller gear is connected to the larger gear by a chain. While a result, as the larger gear turns, the smaller gear, which is following the larger gear, increases its speed and multiplies it to a higher intensity. Though the speed achieved at the larger sprocket wheel is lower due to the rotating motion, the end speed achieved is greater since the power is passed through gears. This speed is adequate to rotate a generator's rotor and is fed into a generator's rotor. The electric motive force is produced when a rotor rotates within a static magnetic stator, cutting the magnetic flux surrounding it (e.m.f). The created e.m.f is then transferred to an inverter, which regulates the generated e.m.f. This regulated e.m.f is now transmitted to the storage battery, where it is held throughout the day and can be used to power street lights at night. "Electricity plays a very vital part in our lives," the study concludes. The current power generation capacity has become insufficient to meet our needs as a result of population growth. In this project, we learn about a reliable system for generating power from speed breakers, and how this technique can help us conserve natural resources. This will prove to be a big help to the world in the future days, as it will save a lot of electricity from power plants that would otherwise be spent on street lights. Because traditional resources are rapidly disappearing, it's past time to consider alternate options. We needed to save the energy we acquired from traditional sources in order to put it to good use. As a result, this concept not only gives an alternative, but also contributes to the country's economy.[46].

CHAPTER 3

Methodology and Design Analysis

3.1 Introduction

This chapter provides two categories namely, the methodology or the procedures followed to realize the aim of document and detail analysis of the design system along with the data collection and analysis methods.

3.2 Methods

A design framework requires two phases with a useful empirical formulation and calculation; this will prove to be a big advantage to the globe in the future days, as it will save a lot of power plant electricity that would otherwise be spent on street lighting. Because traditional resources are rapidly decreasing, it is imperative that alternate supplies be considered. We needed to save the energy we acquired from traditional sources so that we could use it more efficiently. As a result, not only does this concept present an alternative, but it also contributes to the country's economy. MATLAB is a language of computing that in one setting assimilates programming, computing and visualization. [47]. This chapter describes in two phases in detail. The studying of this thesis work follows the following main basic scientific and engineering procedures.

3.3 Design Procedure

Previous studies like journal papers, online articles, books and conference papers are reviewed for the design of EV. This provides evidence of familiarity with the areas covered in this thesis work. Five stages are adopted to achieve the thesis aim. A summary of the stages used in design procedure of this thesis work is given below.

Stage 1: Data collection and analysis. At this stage main dimensions of clutch and specifications of Toyota 3L manual transmission are identified.

Stage 2: Analysis of power requirement and battery size. At this stage, mathematical modeling and sizing equations for the motor and battery are carried out to determine the power requirement.

Stage 3: Design the alternator and analysis parameter. At this stage, alternator is introduced and line and phase voltage calculated and effective voltage required to charge the battery are calculated. These values are then used as an input to calculate the magnitude of electromagnetic circuit constraints. Then loses in alternator are defined.

Stage 4: Modeling and simulation Using Matlab software. Here, model electric vehicle and battery, and the result are explained.

Stage 5: Analyzed the system behavior. At this stage, set of design electric design behavior are carried out.

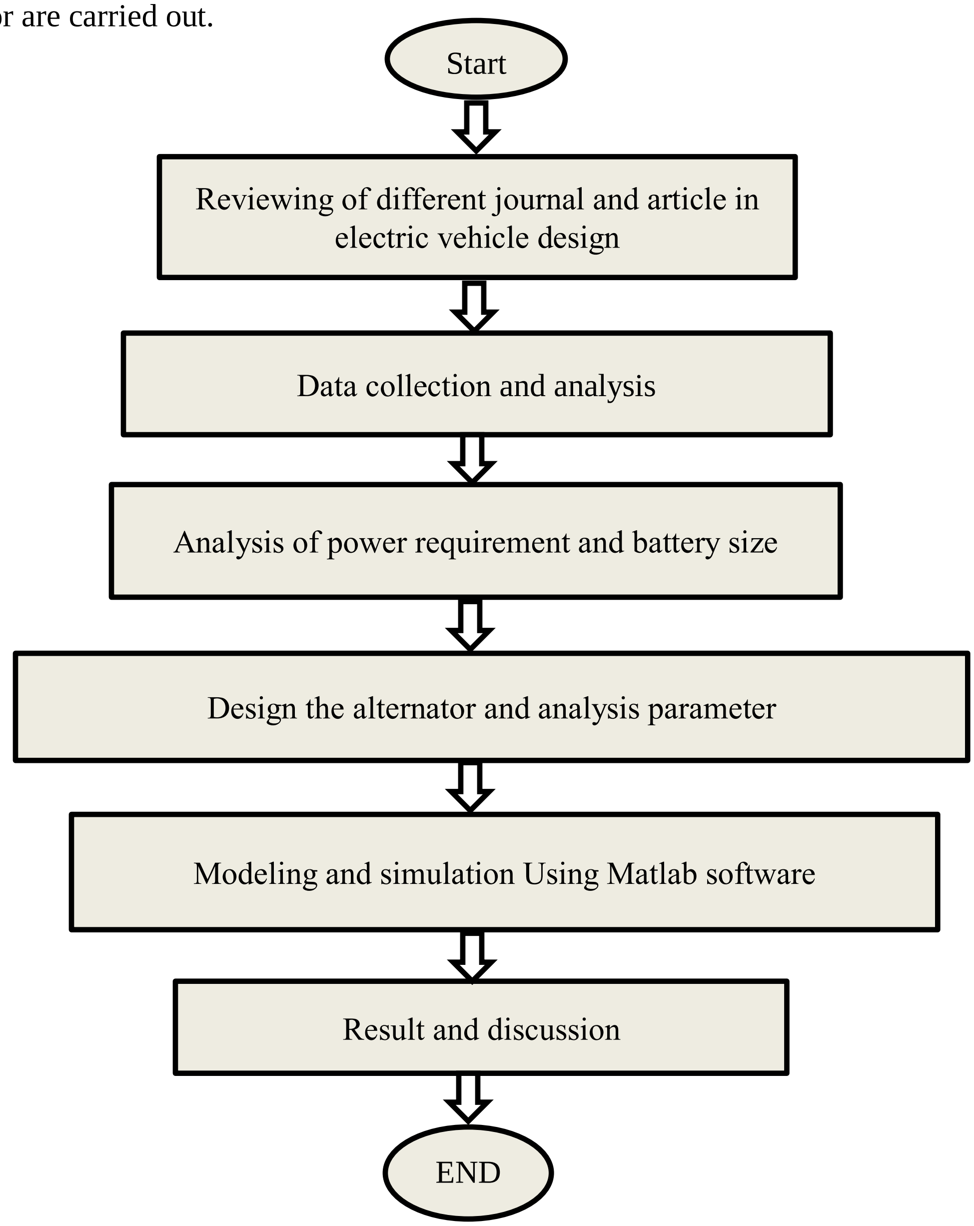

Figure 3. 1: Shows flow chart of design procedure

Phase I

Electric Vehicle Powertrain and Dimension Analysis

An electric vehicle's (EV) powertrain comprises of an electric driving system and a battery that serves as an energy buffer. Typically, only one electric machine, usually three phase AC, is connected to the wheel shaft via a gearbox and differential. However, some applications, such as hub wheel motors, may make use of many electric machines. The energy is chemically stored in a battery, which is electrically coupled to the machine by a DC/AC power electronic converter with a control system. The frequency and magnitude of the three phase voltage applied to the electric machine are controlled by the control system, which is dependent on the driver's current request, which is conveyed via the accelerator and/or brake pedal. In most vehicle applications, it is preferable to make the electric machine's physical volume as small as possible. This can be accomplished by designing it for faster speeds. A maximum speed of 12000 to 16000 rpm is an acceptable compromise.[48], because it provides an excellent balance of volume and performance Nonetheless, during normal on-road driving, a vehicle's speed range can fluctuate from zero to around 130 km/h, or even greater at times. This indicates that the wheels will spin at 1200 rpm or greater. As a result, a reduction gear ratio geared toward the wheels is required. A differential must also be linked between the wheels to allow the left and right traction wheels to spin at slightly different rates during turning. A final gear ratio is sometimes included in the differential. The vehicle's structure and key dimensions are depicted in the diagram below.

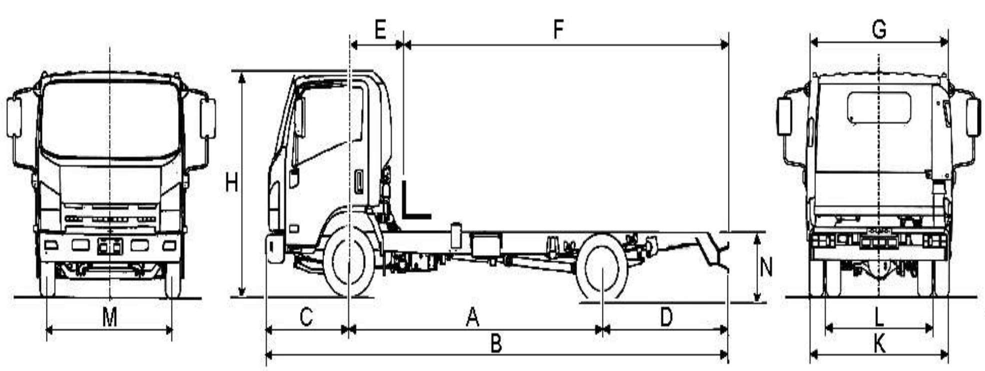

Figure 3.2: Vehicle structure and dimension [www.isuzu.com].

Table 3.1: Vehicle specification

A=wheelbase	2800
B=Maximum length	5392
C=Front Overhang	1119
D= Rear Overhang	1473
E= Front axle body start point distance	710
F=Usable frame length	3563
G= Body Width	2040
H=Maximum Height	2215
K=Rear axle width	1915
L=Rear Track Width	1485
M=Front track width	1680
N= Chassis Height	800

3.3.1 Vehicle Power Train

A Battery Electric Vehicle's (BEV) powertrain comprises of an electric drive system and a battery that serves as an energy buffer. Typically, only one electric machine, usually three phase AC, is connected to the wheel shaft via a gearbox and differential. However, some applications, such as hub wheel motors, may make use of many electric machines. The energy is chemically stored in a battery, which is electrically coupled to the machine by a DC/AC power electronic converter with a control system. The frequency and magnitude of the three phase voltage applied to the electric machine are controlled by the control system, which is dependent on the driver's current request, which is conveyed via the accelerator and/or brake pedal. [49]

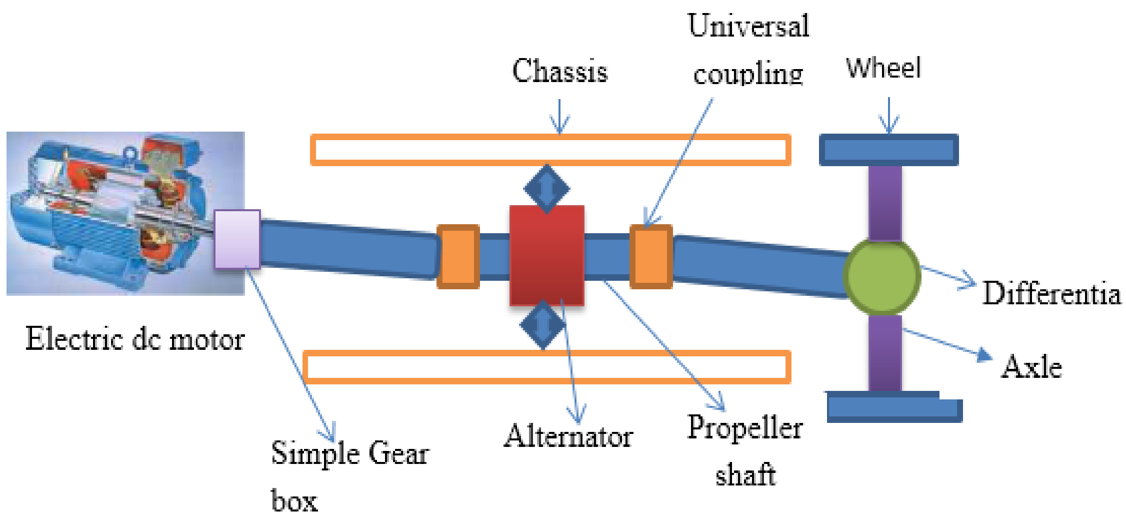

Figure 3.3: Powertrain of the vehicle

3.3.2 Determination of Motor Size

Dc motor are of simple construction, reliability, ruggedness, high starting torque, high power density, and ability to operate in hostile environments. Table 3.2 lists weight factors in efficiency, weight, and cost of four types of motor drives, where 5 marks represent the highest efficiency, lowest weight, and lowest cost, respectively.

Table 3.2: Comparisons between four types of electric motor drives [50]

Index	DC motor drive	IM drives	PM BLDC motor drives	SRM drives
Efficiency	2	4	5	4.5
Weight	2	4	4.5	5
Cost	5	4	3	4
Total	9	12	12.5	13.5

The above table indicates that DC motor drives will continue to be used in EVs because DC motor drives are available at the lowest cost. From the point of view of efficiency, PM BLDC motor drives are the best choice. [50]. The weight of an electric vehicle is one of the factors that might influence its dynamic and range characteristics. When converting an internal combustion engine car to an electric vehicle, the batteries and their placement can be changed. Various types of batteries can be found in electric vehicles. Lead (PbA), nickel (NiMH), and lithium (Li-Ion) batteries are commonly used in electric vehicles. Today, electric vehicles have lithium-ion batteries, yet slow-moving electric vehicles are equipped with lead batteries as well. Lead batteries increase the weight of an electric vehicle the most, compared with the other kinds of batteries. [51] Power requirement of the vehicle is

Vehicle total load= vehicle load and vehicle goods load+ mass battery =vehicle gross weight=3271kg+829.35kg =4100kg

Table 3. 3: Technical parameters electric automobiles.

Parameter	Quantity
Battery weight, kg	829.35
Gross Vehicle Weight(GVW)	4100Kg
Number of wheels per axle	For front wheel 2
	For rear wheel 4
Gravitational acceleration	9.81 m/s^2
Frontal area	3.7212 m^2
Drag coefficient	0.7
Air density	1.185 kg/m^3
Vehicle speed	120km/h

To estimate the energy consumption of a vehicle for a future journey, first determine the road conditions, load on the vehicle, weather conditions, and driving speed, and then calculate the energy consumption from the required amount of energy. The road load, which combines rolling resistance (r), aerodynamic drag force (air), road slope force F(g), and acceleration force F, influences the movement of a vehicle on a road (a). When a vehicle travels at a constant speed, the driving force, or tractive effort, applied to the wheels must exactly balance the sum of all opposing variable forces.

A simplified vehicle model is used to compute the battery power and energy needed to follow various driving cycles. The power required to propel the vehicle is defined in equation 3.1.[52].

$$F(total) = F(rolling\ ) + F(gradient) + F(aerodaynamic) + F(accleration) \quad (3.1)$$

Rolling resistance

During rolling, a number of distinct processes occur in and around the car tires, resulting in rolling resistance. One of the most significant impacts is that repeated deflection of the tire creates hysteresis inside the tire material due to track-soil interaction, resulting in an internal force preventing tire motion and thus resisting vehicle forward motion. Nonetheless, rolling resistance is dependent on a variety of factors, making analytical modeling of rolling resistance extremely complex. Therefore, the rolling resistance force, Fr acting on a vehicle in the longitudinal direction, is usually expressed as the effective normal load of the vehicle multiplied by the dimensionless rolling resistance coefficient Cr as expressed in equation 3.2.[53].

$F_{rolling} = C_r*m*a$……………………………………………………….………………(3.2)

Empirical studies show that the Cr value depends on factors such as; tire material and design, but also tire working conditions such as inflation pressure (Cr decrease with increasing pressure), tire temperature (Cr decrease with increasing temperature), road surface (structure, wet or dry) and speed (Cr increase with increasing speed)[54]

C_r= coefficient of rolling resistance 0.01;

m= vehicle gross weight in kg that is 4100 kg; and

a=acceleration due to gravity (m/s^2) 9.81 m/s^2

$R_{r=}$ 0.01*4100*9.81 N

R_r=402.21 N

The power required to overcome this rolling resistance =$F_{rolling}$*(velocity of vehicle in m/s)

=402.21*120(1000/3600)

=13406.85 watts

Gradient resistance

In addition to rolling resistance, a vehicle suffers gradient resistance while ascending uphill. This gradient resistance increases as the gradient increases, and a vehicle with sufficient power will continue to climb until it slips back due to a lack of ground traction. A vehicle's gradability is the maximum grade that a vehicle can climb at a certain speed while using the maximum power from the powertrain is given by equation (3.3). [53].

$F_{gradient}$ = W sinθ…………………………………………………….………… (3.3)

Consider $\theta=0^0$ when the vehicle travel in flat surface.

So, the gradient resistance at this time is 0 N

Aerodynamic drag

Air, like water or any other fluid, provides resistance to the flow of bodies through it. The movement of air around and through the vehicle, sometimes referred to as external and internal flows, causes the aerodynamic drag that all vehicles are subjected to while traveling. The force exerted by air on a moving automobile has two components:

- The one in the direction of motion called 'drag' F_D
- The one in the direction perpendicular to the motion is called lift F_L.

The body profile of an automobile indicates that the lift force F_L is zero or negligible, and equation 3.4 give total force on the body (drag force F_d). The viscosity and density of air are mainly responsible for drag on the body. The magnitude of this resistance is dependent directly upon the shape and frontal area of the body exposed to the fluid it is passing through, and to the square of its velocity. [53].

F_d= 0.5 * ρ *a*v^2 *c_d*A_f………………………………………………………… (3.4)

Temperature, humidity, and pressure all affect air density, with the latter indicating an altitude dependence. The density value of 1:225 kgm^3 is frequently used in comparative studies, as it represents standardized circumstances such as dry air at 15 c^o at standard atmospheric pressure 1013:25 Pa, i.e. at sea level. [55]. The air density is determined by pressure, relative humidity, and ambient temperature, with humidity having only a minimal effect at higher temperatures. [56].

Where ρ= density of the air medium

$$\rho = \frac{Po}{R*To} = \frac{101325}{287*298} = 1.185\text{kg}/m^3$$

ρ = 1.185 kg/m^3 for air at sea level

v= velocity of vehicle in m/s

c_d= drag coefficient of air resistance 0.7

A_f = Frontal area of the vehicle in m^2

Approximately the width of the vehicle is 1680 mm and the height of the vehicle is 2215 mm. This two are important parameter for frontal area calculation.

Fontal area A_f= width * height*adjusting value

Where Adjusting value are rounded corners for commercial vehicle is 100%

Frontal area A_f = 1.68*2.215*1=3.7212 m^2

So from this aerodynamic drag is = 0.5*1.185 kg/m^3*(33.33 m/s)^2*0.7*3.7212 N

=1714.818 N

Power required to overcome this air resistance = 1714.81*(velocity of vehicle in m/s)

= 1714.81* 33.33 = 57160.276 watts

<u>Acceleration resistance</u>

This is inertial forces required for acceleration the vehicle is defined in equation 3.5.[53]

$F_a = \lambda Ma$……………………………………………………………………..(3.5)

Where λ = rotational inertia coefficient which expresses the proportion of mass that is rotary. It is gear dependent. For direct contact its 1.1

M= Vehicle Gross Weight

a=acceleration of the vehicle

The vehicle reaches its maximum speed in 1 sec and its maximum speed is 120 km/h

From the relation $at = v$ $a = \frac{v}{t} = \frac{33.333\ m/s}{60s} = 0.555 m/s^2$

$F_{a=}$1.1*4100*0.555 m/s^2 = 2255 N

The power required to overcome this acceleration resistance is

*2255*33.333=74415 Watts*

So, total power required to overcome this resistance force will be equal to total power required to move the vehicle. i.e. power needed for motor is 13406.85 watts +0 watt+ 57160.276 watts *74415 Watts* =144982.1261 watts≈ 150 kw.

This means 150 kw motor is required.

Equation 3.6 shows the mathematical model of PMBLDC Motor which is similar to that of a conventional DC Motor and also indicate the differentials equation of PMBLDC Drive describing the response of electrical quantities.[36]

$$V = iR + L\frac{di}{dt} + E \quad (3.6)$$

Where,

V= DC voltage in Volts

L= Inductance of windings in Henry

R= Resistance of the windings in Ohms

E=Kb*w= Back e.m.f of the motor

w=Speed in red/sec

The total electromagnetic torque of Brushless DC Motor T_e in Nm can be expressed in equation [36]:

$$T_e = \frac{P}{w} = \frac{P}{\frac{2\pi}{60}n} \quad (3.7)$$

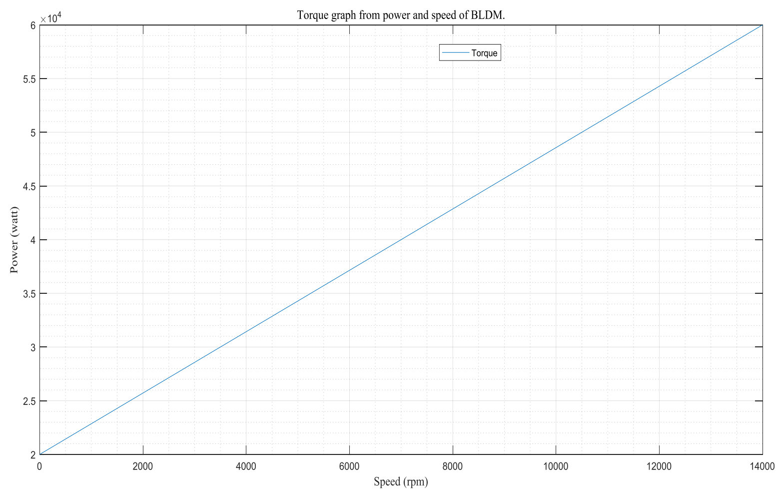

Figure 3.4 Figure Torque of BLDCM.

Speed Control of BLDC motor

When compared to a DC motor, the BLDC motor employs an electric controller rather than a mechanical controller, which makes it more reliable. Because rotor magnets generate rotor magnetic flux in BLDC motors, they are more efficient.[7]. Because of their superior performance in terms of high efficiency, quick response, and weight, precise and accurate, it has been conceivable. [57].

Block Diagram of the Control System

Figure 1 shows a block diagram of a BLDC drive system. A three-phase inverter, position sensors, a signal conditioner, and a digital controller make up the system. The controller of a dc motor is functionally comparable to the inverter and position sensor configuration. A BLDC motor's commutation is regulated electronically. To rotate the motor, the stator windings must be ignited in a specific order.

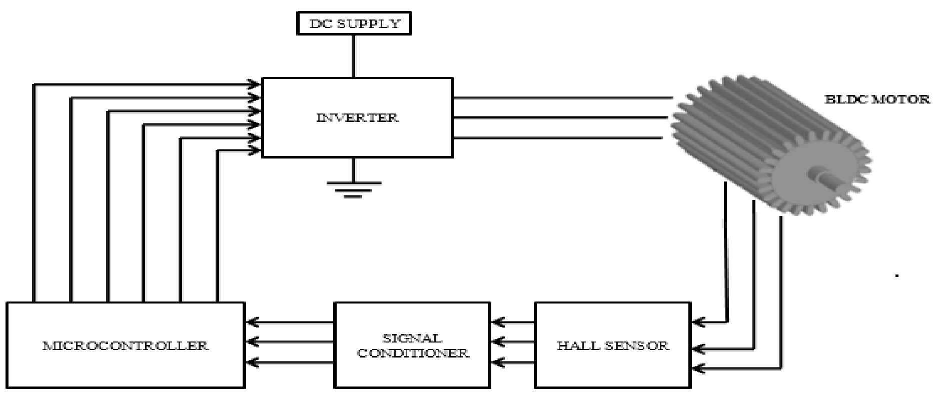

Figure 3.5: Block diagram of BLDC drive system [57].

In order to swap the windings in the correct order, the rotor position must be known. A permanent magnet brushless dc motor has a mechanism for detecting the position of the rotor. Hall sensors in the BDLC motor detect the rotor's position. For position data, three sensors are necessary. Six possible commutation sequences might be obtained using three sensors. Three Hall sensors are inserted within the motor, positioned 120 degrees apart, in the Hall sensor approach. Based on the polarity of the magnetic pole closest to it, each Hall sensor produces a High or Low output. The outputs of all three Hall sensors are analyzed to determine the rotor position. The voltages to the motor's three phases are switched based on the output from hall sensors. The control technique for Hall sensor-based commutation is basic and straightforward to comprehend. The motor can also be run at very low speeds using Hall sensor-based commutation. The microcontroller controls the torque and speed of the motors. To solve the algorithms required to generate Pulse Width Modulated (PWM) outputs for motors, enough processing power is required. The speed of a motor can be controlled simply by adjusting the voltage across it. Changing the duty cycle of the PWM signal can easily vary the motor voltage when utilizing PWM outputs to operate the six switches of the three-phase bridge. Closed loop control regulates the speed of the motor by directly adjusting the duty cycle of the PWM signals that direct the motor-drive circuitry, which is why three-phase BLDC speed control is done using closed loop designs.

Mathematical Modeling BLDC motor control

This paper's BLDC motor is a three-phase, four-pole motor. The sole difference between a synchronous machine with permanent magnet rotor and a BLDC motor is the rotor structure, which causes the machine's dynamic characteristics to alter and the three phase voltage source to be fed to the motor. The source does not have to be a sinusoidal square wave; any wave shape can be utilized, as long as it does not exceed the maximum voltage limitations. The following are the modeled equations (3.8-3.10) for armature winding [84].

$$V_a = R i_a + L\, di_a/dt \quad (3.8)$$

$$V_b = R i_b + L\, di_b/dt \quad (3.9)$$

$$V_c = R i_c + L\, di_c/dt \quad (3.10)$$

Where,

L- Armature self-induction in [H];

R-Armature Resistance in [Ω];

Va, Vb, Vc- Terminal phase voltage in [v];

Ia,Ib,Ic- Motor input current in [A]; and

3.3.3 Determination of Battery

This section of the thesis discusses battery choices in terms of cell size, shape, and size. For electric vehicles, battery packs are one of the energy storage and key sources of energy devices (EVs). The structural complexity of the battery must be increased with arrays of thousands of cells in order to generate maximum power. Despite the fact that Li-Ion batteries are already in advanced development, theoretical values derived through research are near to reality. The lithium-ion battery is now the most well-established technology for BEVs. A lithium-ion battery is made up of interconnected cells that vary in length, breadth, and height, as well as shape (pouch, prismatic, and cylindrical) depending on the manufacturer. Tesla, for instance, uses cylindrical cells, while BMW uses prismatic cells and Nissan uses pouch cells. [58]. To decide the size or number of lithium ion cell of battery for charging 150 kw BLDCM.

3.3.3.1 Weight of Battery

Energy capacity per unit battery weight for electric vehicles (EV) is very high from 60 to 96 Wh kg-1. If an automobile is equipped with 20 kWh lithium batteries, their weight might reach 200 kg.[51]. If an electric vehicle is outfitted with lead batteries and has a range of 60 kilometers per charge, the vehicle's weight can approach 1,700 kilograms. The trip range improves to 170 km if the electric vehicle is supplied with more batteries and its weight is increased to 3,500 kg. The weight of an automobile approaches 1,350 kg, and the weight of its batteries is around 150 kg, to get a range of 100 km per charge when utilizing modern lithium-ion batteries. In order for an electric automobile to achieve a travel range that is similar to the travel range of internal combustion engine automobiles and exceeds 400 km, the weight of the electric automobile has to be increased to 2,000 kg [59]. The energy storage device in electric vehicles, the battery, is many times heavier than the fuel tank; also, its weight is constant regardless of the battery's charge level - whether it is fully charged or totally depleted [51].

The maximum speed of vehicle

V= 120 km/h=33.333 m/s

Vehicle gross weight=4100 kg

Based on the above parameter the power required to overcome the net force is 150 kw

Know lets calculate the energy usage according to the range.

<u>Single cell voltage.</u>

The power supply Lithium cobalt oxide ($LiCoO_2$ or LCO), lithium manganese oxide ($LiMn_2O_4$ or LMO), lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$ or NMC, NCM, CMN, CNM, MNC, MCN), lithium iron phosphate ($LiFePO_4$), and lithium titanium can all be used to make lithium-ion batteries ($Li_4Ti_5O_{12}$)[30]

Table 3.4: Lithium-ion battery voltage [30]

Battery type	Voltage [V]		
	Lowest.	Nominal.	Max.
$LiCoO_2$	3.0	3.6	4.2
$LiMn_2O$	3.0	3.7	4.2
$LiNiMnCoO_2$	3.0	3.6	4.2
$LiFePO_4$	2.5	3.2	3.65
LiNiCoAIO2	3.0	3.6	4.2
$Li_4Ti_5O_{12}$	1.8	2.4	2.85

The equation 3.11 shows the energy consumed by the vehicle in traveling a certain distance in time.

$$\text{Energy usage(Wh) } E = P * T \quad (3.11)$$

$$T = \frac{D}{V} \quad (3.12)$$

Where T= Time required to cover the distance

D= Range or distance covered let take the distance 240 km

T= 240/120= 2 Hr

E= 169.4*2= 338.8 kwh.

Under particular conditions, the battery capacity represents the greatest amount of energy that can be retrieved from the battery. This unit can be expressed in either ampere hour (Ah) or watt hour (Wh), however electric vehicles prefer the latter. Given that the capacity of an electric vehicle's battery is a critical factor because it has a direct impact on the vehicle's autonomy, the development of new technologies that enable the storage of a greater amount of energy in the shortest amount of time will be a critical factor in the success of this type of vehicle. [60].

Net battery capacity for required for driving 150 kw motor for one (1)hour is 150 kWh. The gross battery pack capacity is given by in equation. [*61*].

Gross Battery Pack Capacity = 1.07 * *Net Battery Pack Capacity*…………………………………………………………….……………. (3.12)

=*1.07*150 kWh*

=*160.5 kWh*

The charge capacity of the battery pack can define as follows

$$Charge\ capacity(Q) = \frac{E}{V} \quad (3.13)$$

$$Charge\ capacity(Q) = \frac{E}{V} = \frac{338800Wh}{3.7V} = \frac{338800VAh}{3.7V} = 91567.567Ah$$

Cells with a cylindrical shape Long strip of cathode, separator, and anode foil are rolled together and inserted into a stiff stainless steel or aluminum cell housing or "can" to make Li-ion cylindrical cells (Figure 3.5). The electrodes are welded to the exterior battery terminals after the can is filled with liquid electrolyte and safety disks are put into the top (in this case, the top and bottom of the cell). By crimping the top disk assembly shut, the cell is hermetically sealed. [62].

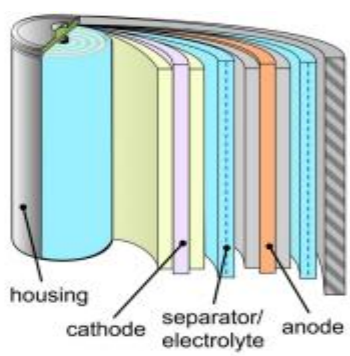

Figure 3. 5: Simplified cylindrical cell diagram [62].

For cylindrical lithium ion cell Cc= cell capacity= 2.5 amp-hr

Vc= cell voltage= 3.7 V

Her the size of the battery pack is decided.

Battery voltage V_b= 350 V or 0.3 kV

The relation between battery power, current and voltage are described in equation (3.14) below.

$$P = VI \quad (3.14)$$

To calculate the current $I = \frac{P}{V} = \frac{180000}{350} = 514.28A$

To estimate how long the battery can sustain this current.

$Q = I * t \Rightarrow t = \frac{Q}{I} = \frac{91567.567Ah}{514.28A} = 178.05h$

Know can calculate the total number of cell (Ct) for the vehicle and its configuration. The battery pack consists of the series and/or parallel configuration of elementary cells. Equation 3.15 describes the relation between series and parallel configuration.

$Total\ number\ of\ cell\ Ct = Sc * Pc$……………………………………..…… (3.15)

Where Sc= Cell in serious combination

For this $Sc = \frac{Vb}{Vc} = \frac{350}{3.7} = 94.594 \approx 95\ cells$

Pc= Cell in parallel combination

For this $Pc = \frac{Cb}{Cc} = \frac{482.857}{2.5} = 193.14 \approx 194\ cells$

Therefore the $total\ number\ of\ cell\ Ct = 95 * 194 = 18430\ cells.$

Lithium ion battery has its own cell type standard for diameter and length.

Table 3. 6: Comparison of different design characteristics of 19.2 kWh $LiFePO4$ battery pack using different types of battery cells [63].

Parameter	Battery cell type					
	Cylindrical			Small Prismatic		Pouch
	18650	26650	38120	Small	Large	
Number of cells	4800	2400	720	600	50	600
Weight, kg	192	196.8	255.6	171.0	210	172.5
Volume, $m3$ (closed pack)	0.101	0.105	0.152	0.131	0.120	0.296
Packing density, $cellsm3/$	47524.75	22857.14	4736.84	4580.153	416.667	2027.027
Interconnection weight, kg	1.217	0.621	12.11	10.24	1.164	10.75
Weight of cell holder, kg	81.6	40.8	12.24	10.2	1.0	42.22
Physical density of battery pack, $kgm3/$	2720.96	2268.77	1841.77	1461.374	1768.033	761.723

Cell cost, USD	≈3 - 11	≈ 7-18	*≈20*	*≈20-40*	*≈150-400*	*≈20-40*
Assembly of single cell	360°, 0°	360°, 0°	360°, 0°	360°, 360°	360°, 360°	360°, 360°
α,β Orientation of cell	3.5	3.5	3.5	3.95	5.0	3.95
α,β Orientation of interconnection	180°, 180°	180°, 180°	180°, 180°	180°, 180°	180°, 180°	180°, 180°
Interconnection handling plus insertion time/cell, s	15.72	15.72	15.72	7.72	7.72	15.72
α,β Orientation of cell holder	360°, 360°	360°, 360°	360°, 360°	360°, 360°	360°, 360°	360°, 360°
Cell holder handling + insertion time, s	7.4	7.4	7.4	7.4	7.4	9.4
Interconnection assembly time (two terminals), s	37	37	46.36	29.72	29.72	60.74
Assembly cost per cell (assumed USD 5 per cell)	0.0884	0.0884	0.101	0.0678	0.0692	0.125
Heat generated by contact resistance, $kJ cycle ⁄$(based on NEDC)	2.034	3.935	19.607	23.6747	284.097	34.090
Heat generated by battery pack, $kJ cycle ⁄$(based on NEDC)	219.906	215.670	193.04	215.440	214.304	218.991
Power consumption of cooling fan	1	0.967	0.380	1.837	6.763	0.604

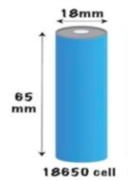

Figure 3.6: 18650 cell type of lithium ion battery.

Model 18650 Cell:

- Weight: 45 grams
- Volume: 660 mm^3
- Capacity: 3.0 Ah / 10.8 Wh
- Density: 240 Wh/kg [mmm]

- Mass of battery pack(kg) is the product between numbers of Lithium ion cell by mass of single cell :
  i.e. $0.045 * 18430 = 829.35$ kg
- Volume of the cell can be calculated from$volum = \pi r^2 h = 3.14(9)^2 * 56 = 16532.1 mm^3$.
  Volume of battery back is the product between numbers of cell by volume of single cell $18430 * 16532.1 = 304686603 mm^3$
- The battery cell energy E_{bc}(Wh) is calculated as:

$$Ebc = Cbc * Ubc$$

$$Ebc = 3.500 * 3.7 = 12.950 Wh$$

Model controller:

For the model battery model in Simulink, P.I controller are used. a P.I Controller is a feedback control loop that calculates an error signal by subtracting the difference between a system's output and the set point, which in this case is the power drawn from the battery.

In discrete time domain the same PI controller is represented by following equations: [83]

$y_n(\text{k } 1) = y_n(\text{k}) + k_i * \text{e(k)}$………………………………………………….. (3.16)

Y_n (k 1) $= y_n$ (k 1) $= k_p$ e(k)……………………………………………………… (3.17)

Where,

k_p= Proportional Gain;

k_i= Integral Gain;

e (k)= Difference in Reference in speed with Actual speed;

Y_n (k 1)= Current computed duty cycle;

y_n(k 1)=Current integrated error term; and

y_n (k)=Previously integrated error term.

3.3.3.2 Battery Condition

This section describes some of the variables used to describe the present condition of a battery.

- *State of Charge (SOC) (%)* – An expression of the present battery capacity as a percentage of maximum capacity. SOC is generally calculated using current integration to determine the change in battery capacity over time.
- *Depth of Discharge (DOD) (%)* – The percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity. A discharge to at least 80 %

DOD is referred to as a deep discharge.

- *Terminal Voltage (V)* – The voltage between the battery terminals with load applied. Terminal voltage varies with SOC and discharge/charge current.
- *Open-circuit voltage (V)* – The voltage between the battery terminals with no load applied. The open-circuit voltage depends on the battery state of charge, increasing with State of charge.
- *Internal Resistance* – The resistance within the battery, generally different for charging and discharging, also dependent on the battery state of charge. As internal resistance increases, the battery efficiency decreases and thermal stability is reduced as more of the charging energy is converted into heat.

3.3.3.3 Efficiency of battery pack

The indication, the heavier weight batteries are used in the electric automobile and the more it is loaded, is used to determine the efficiency of a battery pack used in an electric vehicle. Serial electric vehicles are often equipped with lithium-ion batteries with a range of 120–150 kilometers. Electric vehicles of the latest generation have a tendency to have longer ranges. Because the Eq. (3.18) does not incorporate the battery pack's capacity, the specific weight coefficient for batteries does not fully reflect the efficiency of a battery pack. To compare the efficiency in respect to electric vehicle weight, a specific weight coefficient for batteries has been introduced, which is calculated according to the formula: [51]

$$K_m = \frac{M_{acum}}{M_{ev}} \quad (3.18)$$

Where: $Macum$ electric automobile's battery weight, kg; Mev electric automobile's Weight in kg.

3.3.4 Charging Methods

The way batteries are charged or discharged has a big impact on their safety, longevity, and performance. On-board charging and discharging control are included in today's BMS. Normally, both constant voltage and constant current charging methods are utilized to charge a battery. A charging and discharging model of a Li-ion cell based on the inputs reference is shown in Figure 3.7 which is develop in Matlab. If the cell has not been pre-charged, the battery can be pre-charged at a low, continuous current throughout the early stage. Then it's turned to charge the battery with a higher continuous current. The charging is switched to constant voltage charge when the battery voltage (or SOC) exceeds a particular threshold. Constant voltage charge can be utilized to keep the battery voltage constant after the DC charging supply has been disconnected.[65]

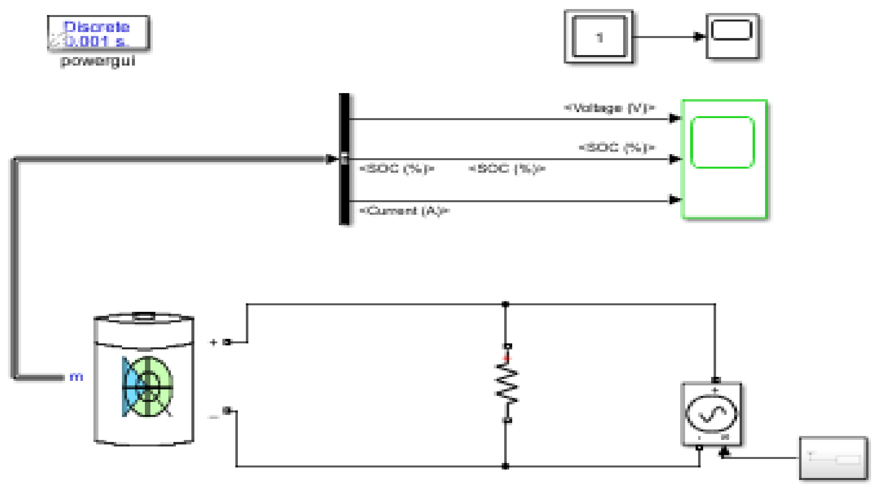

Figure 3.7. Battery charging and discharging model.

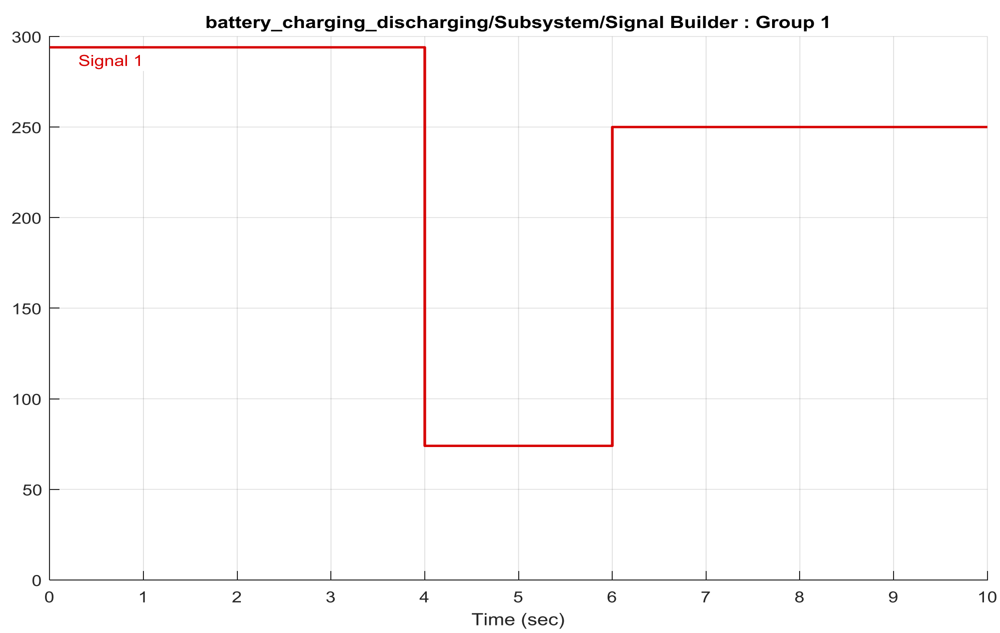

Figure 3.8: Typical Li-ion cell reference charge profile.

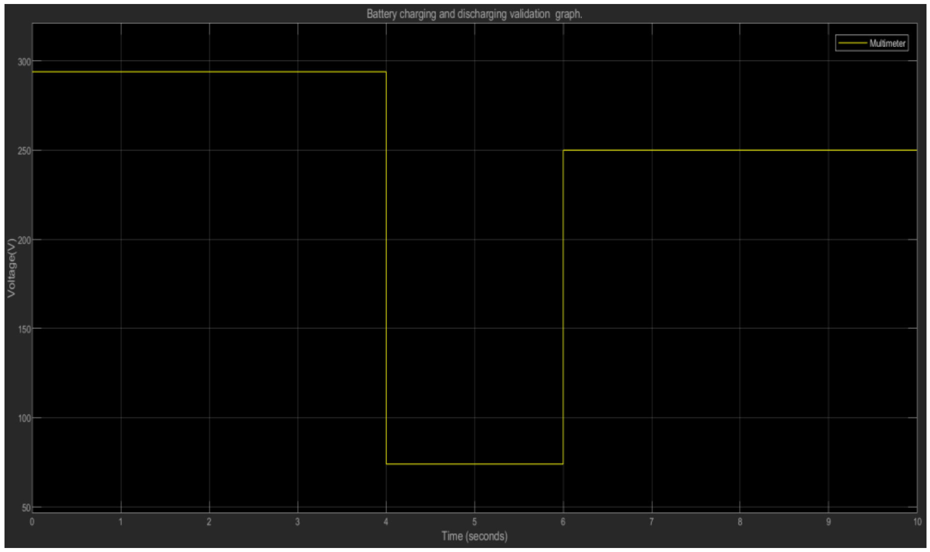

Figure 3. 9 Simulation result of battery charging and discharging model.

The figure 3.9 shows the healthy charging and discharging behavior of lithium ion cell based on the reference input in figure 3.8.

3.3.5 Battery Management System

Because of its zero-emission of hazardous gases and efficient energy use, electric vehicles (EV) are playing a critical role. Electric vehicles have a significant number of battery cells, which necessitate an efficient battery management system (BMS) to provide the required power.

The battery management system (BMS) makes decisions based on the charging and discharging rates of the battery, state of charge estimation, state of health estimation, cell voltage, temperature, and current, among other factors. Because batteries used in electric vehicles should not be overcharged or over drained, the battery management system (BMS) is a critical system in electric vehicles. If this happens, the battery will be damaged, the temperature will rise, the battery's life span will be reduced, and the people who are using it will be affected. It's also utilized to extend the range of a vehicle by efficiently utilizing the energy stored in it.[66]

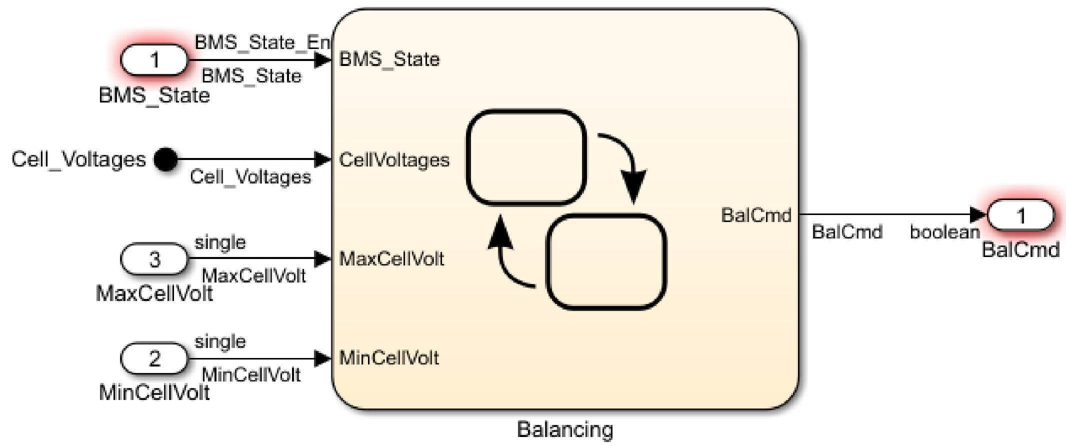

Figure 3.10: BMS block diagram.

State of Charge Estimation

The available amount of battery expressed as a percentage of the battery's rated capacity is known as the state of charge. The ratio between the residual power and the full capacity of the battery is the charge state of the battery (SOC). State of charge assists the battery management system in determining the state of the battery, allowing it to run within a safe operating range by controlling charging and discharging. It also extends the battery's life lifetime. It is impossible to estimate the state of charge directly. It is calculated by using the equation 3.19.[67]

$$SOC = 1 - \frac{\int idt}{c_n} \qquad (3.19)$$

Where I =current and

Cn= maximum capacity that the battery can hold

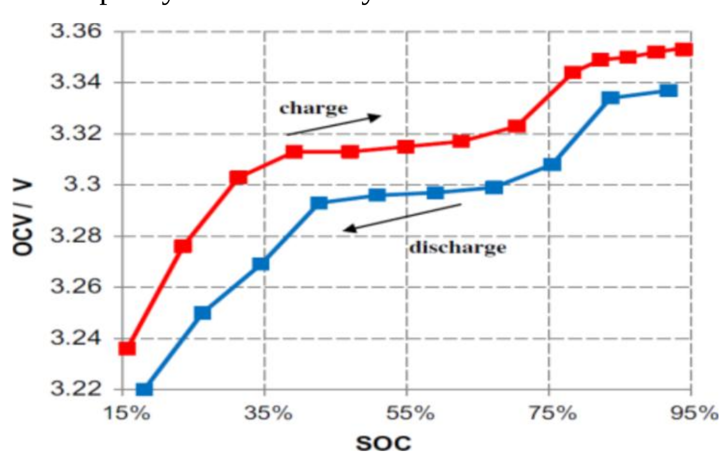

Figure 3.11 SOC during charging and discharging [67].

Depth of Discharge (DOD). The percentage of total battery capacity that has been discharged is indicated by DOD. Deep-cycle batteries can be discharged to 80% or greater of their DOD. The relation between DOD and SOC are described in equation 3.20.

$DOD = 1 - SOC$……………………………………………………………….(3.20)

3.4 Design of Alternator

Phase II

Design consideration of lithium ion battery charger alternator.

Obviously, today's electric vehicles employ battery packs with a large number of cells and a large capacity, which necessitates a higher level of charging safety. For safety concerns, stricter safety regulations are required. When the battery is charging or discharging, the voltage, current, and temperature of each battery cell should be recorded and monitored. This is about the battery's life and safety while in use. As a result, a broader design consideration is required to assure battery safety and effective charging. Because this battery is charged by an alternator, the alternator's design must be cautious in order to meet the battery's safety requirements. To ensure normal communication between the battery and alternator, the battery modules and alternator communicate periodic commands at a set interval of time. Temperature, charging voltages, and charging current are all monitored and recorded. The BMS is in charge of the entire charging process in order to assure battery safety.

3.4.1 Introduction of Alternator

The alternator is a popular piece of equipment in today's autos for charging the battery and starting the vehicle; it's employed not just in tiny cars, but also in agricultural engineering, structural engineering, and stationary generators. They're made in a number of power and voltage levels, and they're always scrutinized from a variety of angles, including dependability, efficiency, size, weight, and cost. The alternator's whole service life is given special consideration.[68]. All generators must have two mechanical elements, a rotor and a stator, in order for relative motion between the conductor and the magnetic field to occur. The Rotor is the rotating component, whereas the Stator is the stationary component. The rotor is always the armature in a dc generator. The armature in alternators can be either the rotor or the stator, but it is always stationary in these designs. [69] A car alternator is a generator that provides electric energy for things like lighting, indication lights, ignition, fuel injection, and other electrical equipment in electric cars. In general, an ac generator or alternator is a device that converts mechanical energy into electrical energy via the electromagnetic induction principle. [14]. for many years, the electrical power requirements of automobiles have been quickly increasing, and this trend is projected to continue. The replacement of engine-driven loads with electrically powered counterparts, as well as the introduction of a wide range of new capabilities in cars, is driving this trend. The constant growth in power demands is stretching the limitations of existing automotive power generation and control technology, driving the development of higher-power and higher-voltage electrical systems and components.[70].

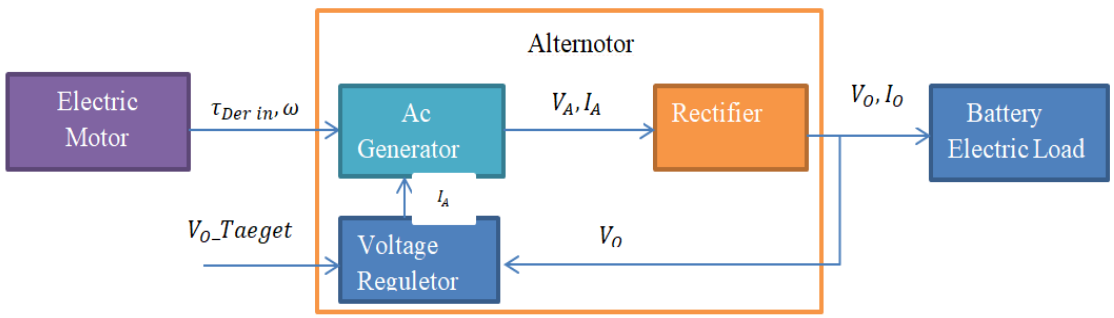

Figure 3.12: General structure of alternator.

3.4.2 Types of Alternator

The ac generator can be divided into different types based on their application, prime mover, design, output power, and cooling. Alternator based on their output Power divided in three:

1. Single phase alternator
2. Two phase alternator
3. Three phase alternator

3.4.2.1 Single Phase Alternator

The single phase alternator generates a single alternating voltage that is constant. The armature coils are connected in series to produce a single circuit that generates output voltage.

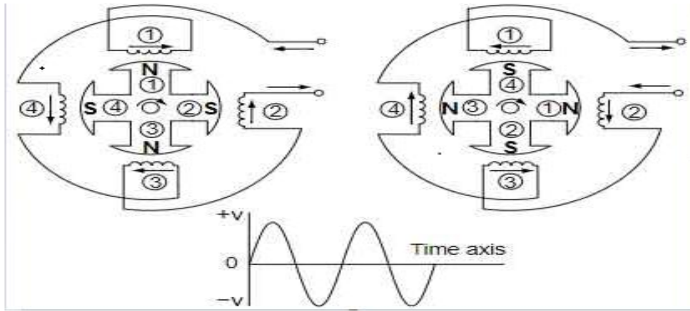

Figure 3.12: Single phase Alternator [71].

3.4.2.2 Two-Phase Alternator

Two single-phase windings are physically separated apart in a two-phase alternator so that the ac voltage induced in one is 90° out of phase with the voltage induced in the other. Electrical isolation exists between the windings.

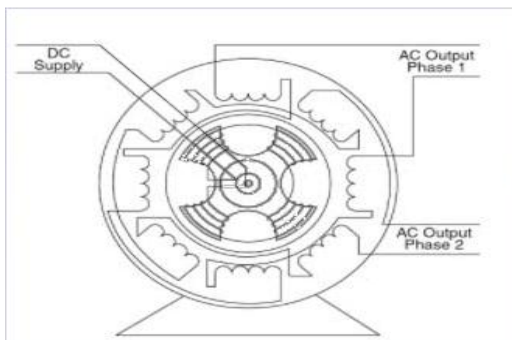

Figure 3.13: Two-Phase Alternator [71].

3.4.2.3 Three Phase Alternator

Three sets of single-phase windings are arranged in a three-phase alternator so that the voltage induced in each winding is 120° out of phase with the voltages in the other two windings. To generate a three-phase output, these windings are connected in a star.

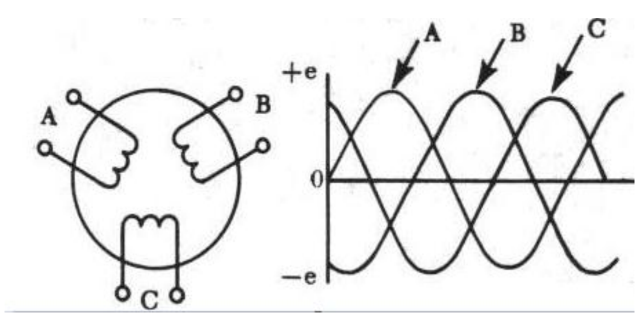

Figure 3.14: Three-phase-alternator [71].

3.4.3 Deatail Construction

The armature and the field system are the two main components of a synchronous machine (alternator). The armature winding is installed on a fixed element called the stator, and the field winding is mounted on a revolving unit called the rotor in normal ac generator architecture.

3.4.3.1 Rotor

A magnetic field is generated by the rotor. Because the movement is known as an alternator with a revolving magnetic field, the rotor revolves along the propeller shaft. A core pole (pole cores), field coils, shaft (which is employed as a propeller shaft for delivering rotational power), and other components make up the rotor. It's shaped like a claw pole core with a field coil within. [72].

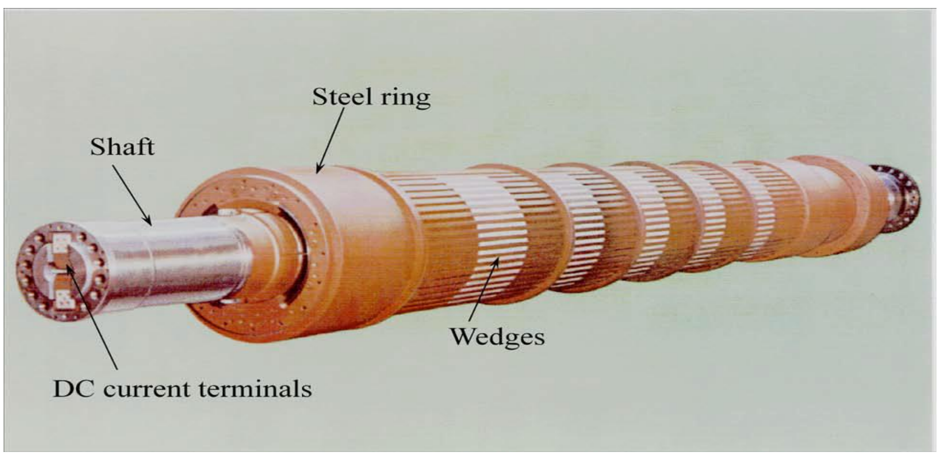

Figure 3.15: Alternator rotor [70]

Two types of rotors are used in alternators

- ❖ Salient-pole type and
- ❖ Smooth-cylindrical type.

Salient (or projecting) Pole Type:

Low- and medium-speed (dc motor powered) alternators employ it. It has a large number of protruding (salient) poles with their cores bolted or slotted into a strong magnetic wheel made of cast iron or high-quality steel. The enormous diameters and short axial lengths of such generators distinguish them. To reduce eddy current heating, the poles and pole-shoes (which cover 2/3 of the pole pitch) are laminated. Field windings in large machines are made up of rectangular copper strips twisted on the edge. [72]

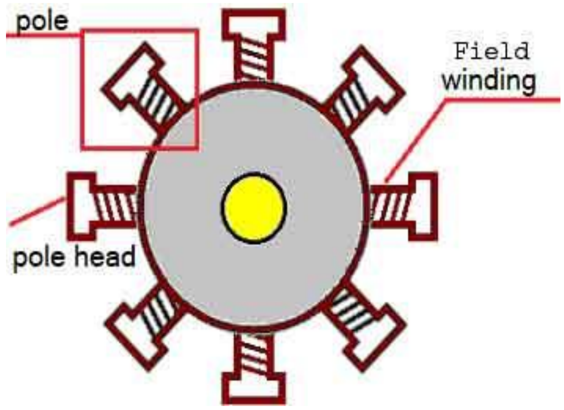

Figure 3.16: Salient (or projecting) Pole Type [72].

<u>Smooth Cylindrical Type or non-silent pole type:</u>

It's utilized in turbo alternators powered by steam turbines that spin at extremely high speeds. A smooth solid forged steel cylinder with a number of slots cut out at intervals along the outside edge makes up the rotor (and parallel to the shaft). These rotors are typically used in 2-pole or 4-pole turbo-generators that run at 3600 or 1800 rpm. [73]

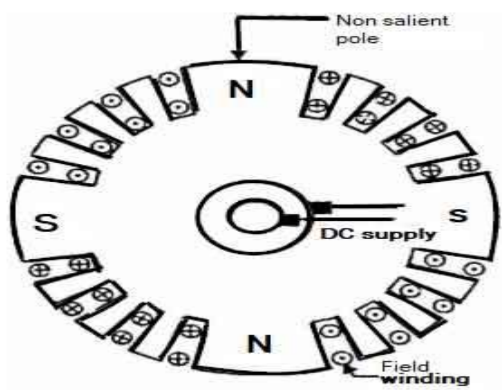

Figure 3. 17: Smooth Cylindrical type [73]

3.4.3.2 Stator

The stator is made up of unique silicon steel alloy laminations with slots on the inner periphery for the conductors known as windings. Because the rotor revolves within the stator, the flux from the rotor cuts the stator's windings, causing an induced electromotive force in the stator's windings. To reduce eddy current losses, the stator core is laminated and protected from each other using silicon-oxide covering. The stator assembly is treated with insulating varnish after windings. [22].

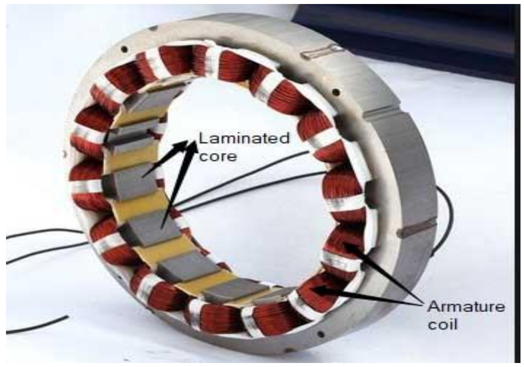

Figure 3. 18: Stator[3]

3.4.3.3 Stator Frame

The outside frame (or yoke) of a d.c. machine assists to convey the magnetic flux, though it is not designed for that function in alternators or dc generators. It's utilized to keep the armature stampings and winding in the right place. Frames are often constructed from mild steel plates that have been welded together to produce a box-like structure.

3.4.3.4 Stator core

The stator frame supports the armature core, which is made up of unique magnetic or steel alloy laminations. Eddy current loss is minimized by laminating the core. Complete rings of laminations are stamped out. The laminations are isolated from one another and have openings between them to allow for the passage of cooling air. The slots for housing the armature conductors run along the core's inner perimeter and are stamped out at the same time as the lamination. [3]. the equivalent circuit model for the alternator is described as bellow in figure 3.15.

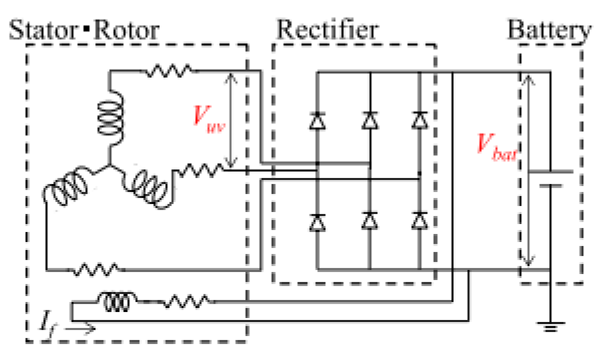

Figure 3.19: Equivalent Circuite model for altornator.[81]

Armature windings

The armature windings in the alternator's circuit winding are open, in the sense that the armature currents do not have a closed channel in the winding itself. The two most prevalent types of armature winding in 3-phase alternators are:-

Double layer winding: Alternator stator windings are typically double layer lap windings with integrated or fractional slot windings. Windings with full pitches or short chords can be used. The benefits of double layer windings are as follows.

(i) Better waveform: by using short pitched coil

(ii) Saving in copper: Length of the overhang is reduced by using short pitched coils

(iii) Lower cost of coils: saving in copper leads to reduction in cost

(iv) Fractional slot windings: Only in double layer winding, leads to improvement in waveform.

Single layer winding: Each side of a coil occupies a slot fully without any other coil on top of it in single layer winding, and the number of coils equals half the number of slots. Because of the tight slots in single layer windings, they are more efficient and quieter to operate. Because the end connections are separated by huge air voids, single layer windings are highly insulated and appropriate for high voltages. Because of the larger space factor, there is no interlayer separator. [74]

The Generated Voltage Equation

A number of coiled coils are subjected to voltage induced by mechanically rotating a magnetic field. That notion is used in all ac machines that convert rotational energy to electrical energy. The relationship between the induced voltage in rms, the number of windings, the rotational speed, the flux of the rotating magnetic field, and the distribution factor is shown in equation 3.21.[75]

$$Eph = 4.44 f \Phi Tph * Kp * Kd \quad \text{..........(3.21)}$$

Kd= Distribution factor

K_c or K_p = Cosα/2 This is pitch factor

Design of stator winding:

The winding of the stator is made up of wrapped copper diamond-shaped coils with a high conductivity. The induced e.m.f in all phases of the coils must be the same amplitude and frequency, hence these windings must be appropriately structured. These e.m.fs must have the same wave shape and be separated by 1200. Single or double layer windings may be used depending on the requirement. The three phase windings of the ac generator are always connected in Wye with neutral earthed.

- Number of Slots**:**

The number of armature slots must be sufficient to achieve a balanced winding. With fewer slots, the number of conductors per slot will be higher, and the internal temperature rise would be greater. Tooth ripples will be smaller in the field form as the number of slots increases, and the width of the teeth will be reduced as the iron losses increase. As a result, peak slot pitch values should be chosen. It is usually chosen based on previous experience. [22]. The number of slots should be carefully chosen because it has an impact on the machine's performance. There are no guidelines for determining the amount of slots available. However, consider the benefits and drawbacks of having a larger number of slots. However, when deciding on the number of spaces, keep the following points in mind.

It should be designed to give the following advantages:

(i) Reduced leakage reactance;

(ii) Better cooling; and

(iii) Decreased tooth ripples.

- Slot loading must be less than 1500 ac/slot
- Slot pitch must be within the following limitations

(i) Low voltage machines ≤ 3.5 cm

(ii) Medium voltage machines up to 6 kV ≤ 5.5 cm

(iv) High voltage machines up to 15 kV ≤ 7.5 cm

Considering all the above points' number of slots per pole phase for salient pole machines may be taken as 3 to 4. So for this designs the number of slots taken as 4.

- **Number of poles**

The number of poles of this alternator is determined from rpm of propeller shaft because it is speed of rotor. And rpm of alternator is get from hp of newly designed vehicle.

$HP = Torque * RPM/5252$

For this vehicle or 150 kw is 203.94 hp and the torque of the vehicle is 320 Nm.

From this value the RPM of the rotor can be calculated

203.94 Hp= 320 Nm*RPM/5252

Speed of rotor is approximate to 3200 rpm

Synchronization of speed of motor and alternator

Frequency of produced electromotive force, speed of brushless dc motor and number of poles are synchronized by the relation [76]

$$Synchronizi\ speed = \frac{120f}{p} \quad \text{..........(3.22)}$$

$$N_s = \frac{120f}{p} = \frac{120 * 50}{p} = 3200$$

P=1.87≈2

The number of slot per pole and phase is in the range of 0.25 – 0.5. In this case the phase coils are, so-called tooth-concentrated double layer coils, being much simpler than the windings for integer slots/pole configurations. [77].

The Rotational Input Speed

When it comes to producing a desired voltage, the input rotational speed is a key aspect. Every rotational AC machine has a specified rotational speed that it is meant to operate at during normal operation. For this specific assume that, car depending on the load and road condition the maximum speed 120 km/h equivalent to motor speed around Ns 3200 rpm and the alternator also spin at same revolution. [73]. For charging the battery take the number of poles 6, the frequency of e.m.f is 60 Hz alternator has 12 slots per pole and four conductors per slots. A flux of 25 m wb is sinusoidal distributed along the air gap.

Number of slots = Number of slots per pols* Number of pols

= 6*12=72 slots

Number of conductors (z) = Number of slots*number of conductors per slots

=72*4= 288

Number of conductor per phase is $\frac{288}{3}$= 96=Z

Turn per phase = $\frac{96}{2}$= 48

Total conductors in all phase (z) = Number of slots per poles*number of poles*number of conductor per slots =12*6*4=288

Number of conductor per phase (Z_{ph}) =2*numbers of turns per phase (T_{ph}) = 96

Hence induced e.m.f can be calculated:-

$Eph = 4.44f\Phi Tph * Kp * Kd$............................ .... (3.23)

Eph = induced e.m.f per phase

Zph = no of conductors/phase in stator

Tph = no of turns/phase

Winding factors (kw)= K_P*K_d = winding factor assumed to be full pitched as 0.955.

$Eph = 4.44 * 60 * 25 * 10^{\wedge} - 3 * 48 * 1 * 0.955$

$Eph = 305.299\ V$

Line voltage =E_l=$\sqrt{3}E_{ph}$ =528.7933V

Effective Voltage(E) = $0.707E_{max}$

The effective voltage used for charging the alternator is:

0.707*528.7933=<u>373.856 V</u>

In this work resistive load consider as active load that is impedance (combination of resistance and reactance)

The load are load impedance (combination of resistance and reactance) 50 **Ω**

Using ohms low $I = \frac{V}{R} = \frac{373.856V}{0.89} = \underline{420.07A}$

Total active power can obtain using the relation

$p_{total} = \sqrt{3}E_L I_L cos\phi$

$P_{total} = \sqrt{3} * 528.7933V * 420.07A * \cos 0$

$p_{total} = 384738.39Watt\ or$ <u>384.739kw</u>

3.4.4 Voltage Regulation

The terminal voltage of a generator varies when the load on it is adjusted, as we've observed before. The degree of variance is determined by the generator's design. The voltage regulator's job is to keep the voltage of the car's alternator at a constant level so that the battery can be charged and the consumers can be supplied. An Otto engine's speed can range from 800 to 6500 revolutions per minute. If the induced voltage is proportional to the shaft's rotational speed [64 78]. The voltage regulation of an alternator is the change of voltage from full load to no load, expressed as a percentage of full-load volts, when the speed and dc field current are held constant.

$$\frac{E_{nL} - E_{fL}}{E_{fL}} * 100 = percent\ of\ regulation$$

3.5 Vehicle weight distribution

Modern lithium-ion batteries are used in electric cars, and current technology allow for travel without the need to recharge the battery at a station. These batteries are not only heavy, but they also take up a lot of room inside the automobile.[51]. The battery pack is the most significant weight component, accounting for roughly 20-25 percent of the overall weight of small vehicles on the market. As a result, shifting the battery pack along the vehicle has a significant impact on mass distribution in both directions. By positioning the battery pack at the front, mid, and back sides of the vehicle, three longitudinal mass distribution ratios of 60:40, 50:50, and 40:60 have been achieved. During cornering, the vehicle's lateral mass distribution is critical for easy maneuverability. Maintaining an equivalent lateral mass distribution on both sides is critical. When the vehicle begins to turn, weight is transferred in a lateral motion to the vehicles outside tires. If the vehicle's mass distribution is not equal on the left and right sides, one side of the tires will experience an inherent amount of weight force during either a left or right turn. [79].

3.6 Block diagram of the vehicle

Block diagram of Battery Electric Vehicle include driving cycle, driving controller, power convertor, motor, vehicle body, alternator and battery. The figure below shows simple electric vehicle block diagram.

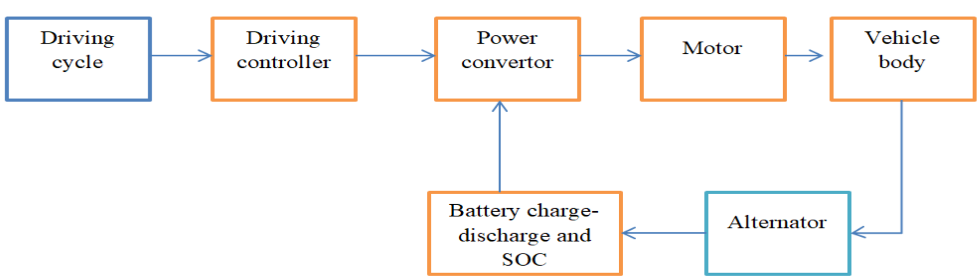

Figure 3.20: bock diagram of electric vehicle.

CHAPTER 4

Results and Discussion

4.1 Electric Vehicle Model

This chapter will explain and present the Simulink modeling of the electric vehicle battery and alternator with different Parameter. Matlab/ Simulink environment software is a tool capable of modeling complete EV powertrains of different levels of reliability and detail and has become an invaluable modeling platform [80]. The Matlab/Simulink platform supports many add-ons which have been used in electric vehicle Modeling. The first model simulation programming of Matlab code is made based on block diagram in figure 4.1. The input for simulation are drive cycle source FTP75(2474 second) standard driving cycle it is explained in the below section and other parameter are tabulated in Table 4.1 , Driving controller that is longitudinal driver, and voltage source that is alternator are used in the model. For the remaining vehicle model subsystems shown in the appendix and then implemented in the simulation blocks and signals within Simulink. And it is developed based on analytical calculated of weight of vehicle, motor capacity, gross battery pack capacity, charge capacity and total power; therefore it can work in any whether condition and moving speed of the vehicle up to 120 km/h.

4.1.1 Step for Simulation

Step 1: Model creation of the system in Simulink;

Step 2: Connecting the element through energetic and data link ups;

Step 3: Defining the model functional parameters;

Step 4: Import the value for the parameter;

Step 5: Define control parameters of the simulation process;

Step 6: Run the simulation, in order to determine the result of the electric vehicle;

Step 7: If the system not run, start from step 1 and analysis the error; and

Step 8: But if the simulation run, take the result from Matlab to document and discuss the result.

Table 4.1: Electric vehicle parameters.

Parameters	Description	Value	Unit
M_v	Vehicle mass	4100	Kg
P	Air density	1.185	kg/m^3
Number of wheel per axle	For front axle	2	
	For rear axle	4	
C_{ro}	Rolling coefficient	0.01	
C_d	Aerodynamic drag coefficient	0.7	
CG	Center of gravity height from the ground.	0.5	M
G	Gravitational acceleration constant	9.81	m/s^2
Battery type	Types of battery cell	Lithium ion	
Capacity	Capacity of battery		160.1 kWh
SOC_{intial}	Initial state of charge	80, 85	Percentage
V	Speed of vehicle	120	Km/h
V	Nominal voltage of the battery	350	V
Battery pack capacity		160	kwh
Output	Output from motor	169	KW
Torque	370 Nm	Torque	Nm

Following is the screenshot of the MATLAB Simulink based on the above input

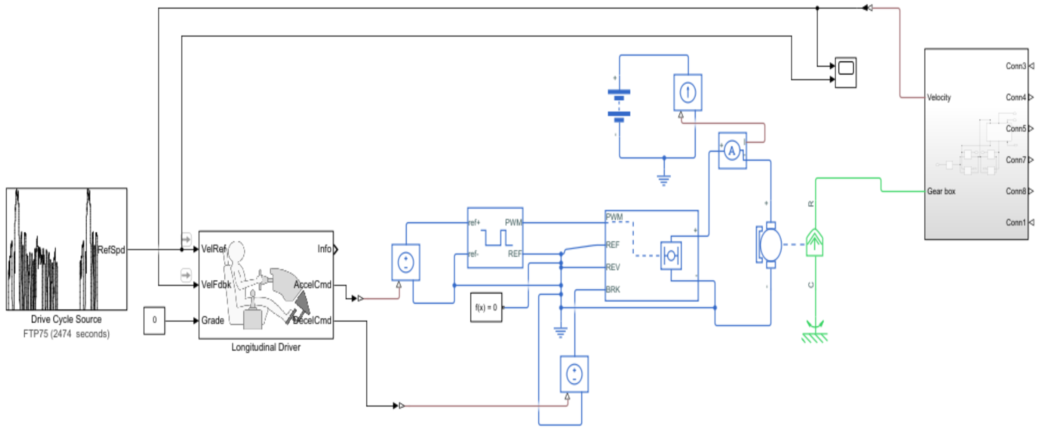

Figure 4.1: Matlab/Simulink electric vehicle model based on drive cycle input, MathWorks: 2020.

The above figure indicate study of the model is in accordance to variation in velocity-time profile (drive cycles). During drive cycles, the vehicle undergoes transiency due to start, stop, acceleration, braking. Thus, with drawing power and energy from the battery packs in order to overcome the resistance offered by the vehicle.

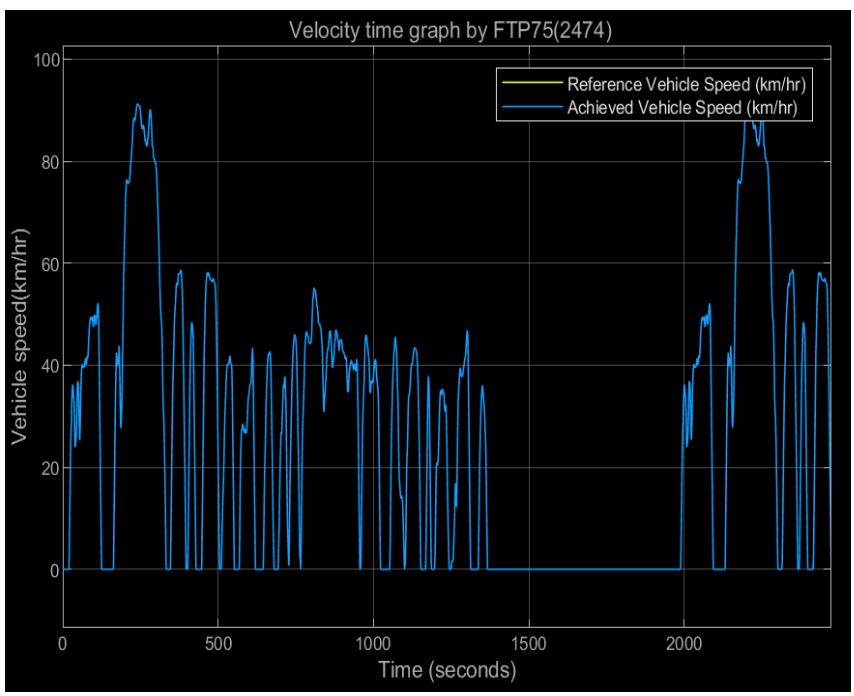

Figure 4.2: Simulation result of Velocity vs Time Graph.

In the above result we observed that yellow curve and Blue Curve almost follow each other or over laid on the drive cycle speed throughout 2474 seconds. The interpretation of the result is that the modeled vehicle is capable of following the drive cycle input closely within a very small margin of error(near to zero) while meeting the speed and torque response.

Overall electrical vehicle model

In the figure 4.3, the overall configuration of electric vehicle are modeled

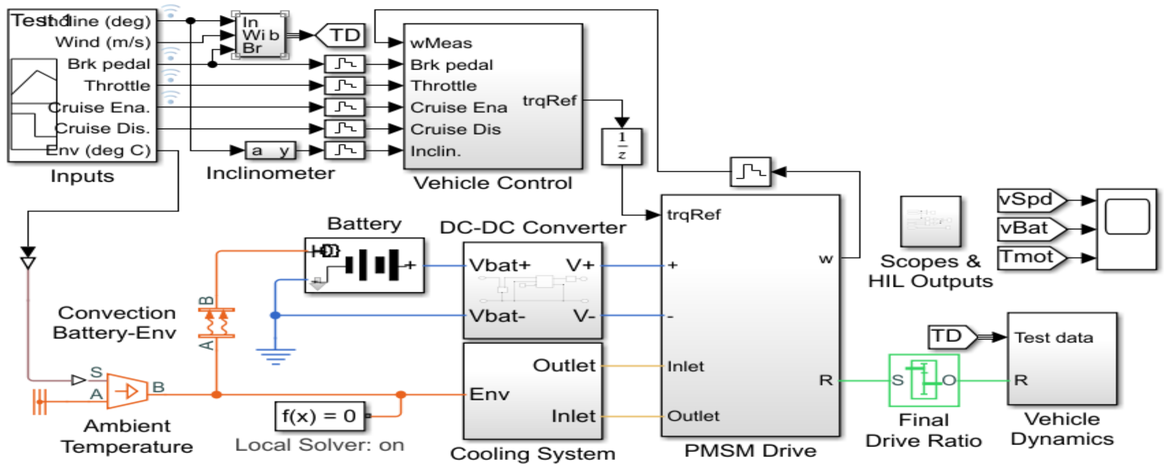

Figure 4.3 Overall Configuration of Electric Vehicle.

The following(figure 4.4) screenshot is the input to drive the above model of elctric vehicle.

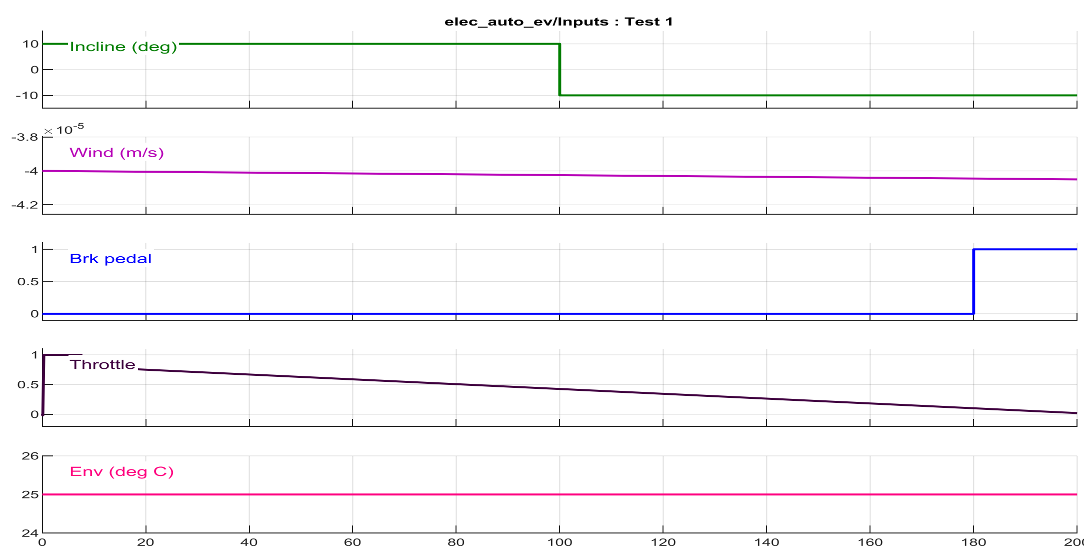

Figure 4.4: Input for Electric vehicle driving.

The figure 4.5 shows the behavior of an electric vehicle subject to driver inputs (throttle) and environmental conditions (road inclination). The vehicle accelerates until the driver the applied the brake pedal after that, the vehicle slows down to zero speed. And motor temperature, which is increase relative to vehicle speed and environmental condition. And the interpretation of this is, the input parameter to vehicle is good and system response also nice.

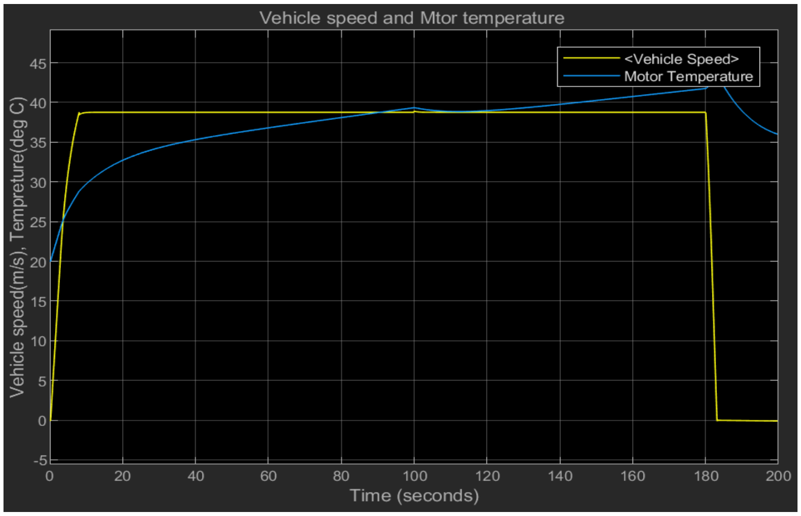

Figure 4.5: Vehicle speed and motor temperature.

The figure 4.6 shows the torque produced by the PMDC motor for this electric vehicle. Torque mainly depend on road condition, during the first half(up 100 second driving) of the simulation the motor is accelerating the vehicle to the commanded speed and then continuing to apply torque to push the vehicle up a hill. During the second half of the simulation, the motor acts as a generator as shown by the change in sign of motor torque.

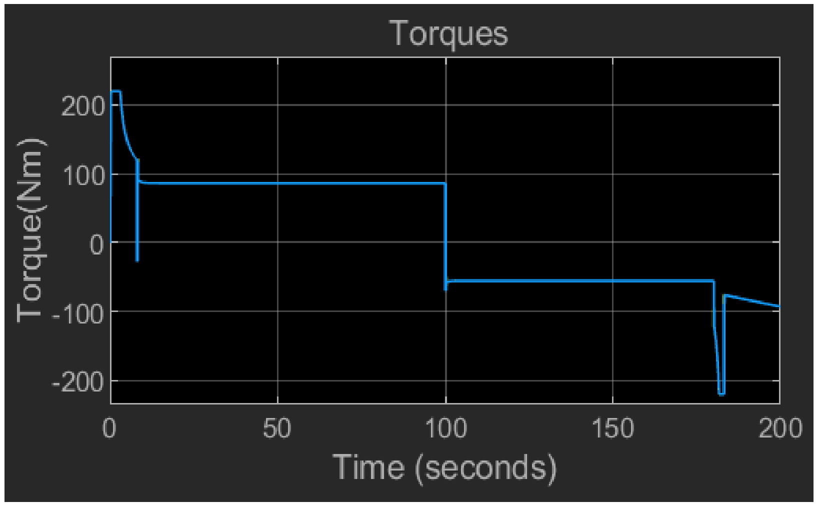

Figure 4. 6: Torque produced from the motor.

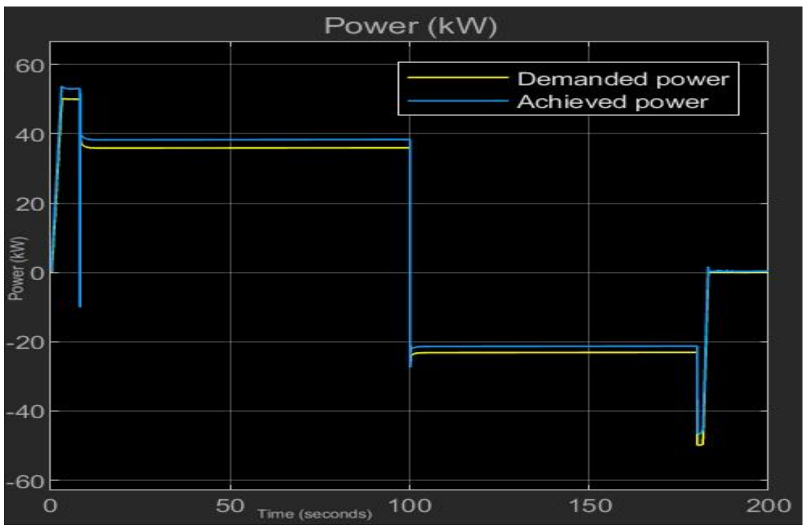

Figure 4. 7: Demanded and Achieved power.

In the above figure, the whole simulation are validating because the achived power is more than demanded power that mean the vehicle can move forward.

4.1.2 Vehicle Body Model

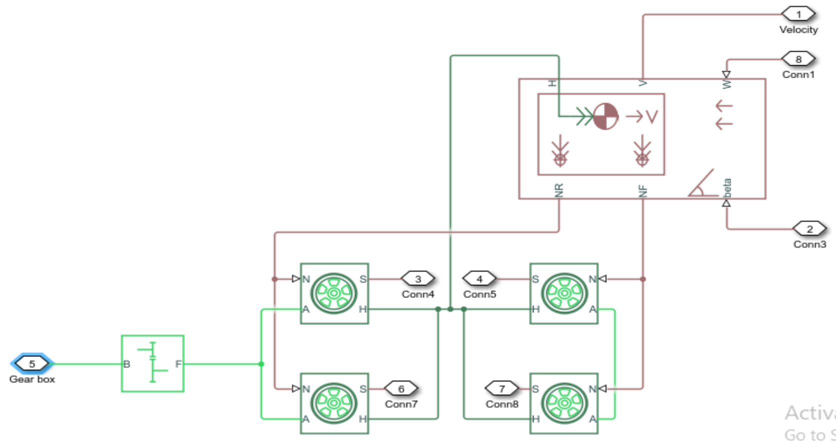

Figure 4. 8: Matlab/Simulink vehicle body model (subsystem)

4.1.3 Electric Motor Model

Electric motors are one of the most important parts of an EV's drivetrain. The parameter definitions for calculating the motor loss model are also listed in the table 4.2.

Table 4.2: Motor model (**EMS-075G8018**) parameters.

Parameter	Units	Description	Value
Vd	V	Voltage	338.6
T	Nm	Maximum motor torque	340
N	Rpm	Rated Speed	3000
N	Rpm	No-load Speed	3450
Ω	rad/s	Motor bases speed	815
Rs	Ω	Stator phase Resistance	2.875
H	H	Armature Inductance	$8.5*10^{-3}$
Number of Poles			4
I	kgm^2	Inertia	$0.8*10^{-3}$
k_c	$\frac{s}{kgm^2}$	Motor loss constant	0.12
k_i	J	Motor loss constant	0.01
k_w	Kg m^2	Motor loss constant	$1.2*10^{-3}$
C	W	Motor loss constant	600

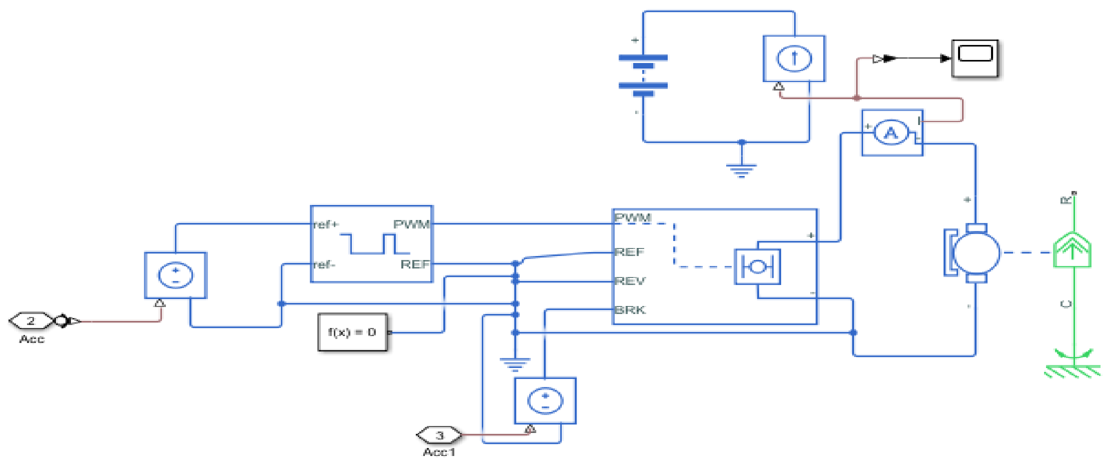

Figure 4.9: Motor and motor controller model.

Permanent Brushless DC Motor Speed Control

Description of the Simulation Model:

The Matlab simulation is carried out with the help of the designed circuit parameters, and the results are shown in figure 4.10-4.14. The rotor speed, stator current and electromagnetic torque control of permanent magnet brushless dc motor can be implemented by hall sensor as described in body the document. A Hall Effect sensor is a long time solution because there are no mechanical parts to wear down over time. The hall sensor control speed of brushless dc motor by controlling the input dc voltage/ current that means the higher the voltage the more speed obtained. In the figure 4.10 speed of brushless dc motor taken as 3200 rpm as reference input at t=0.5 seconds. As can be observed, the phase voltages are 120 degrees apart. The current waveforms of the stator are depicted in figure 4.12.

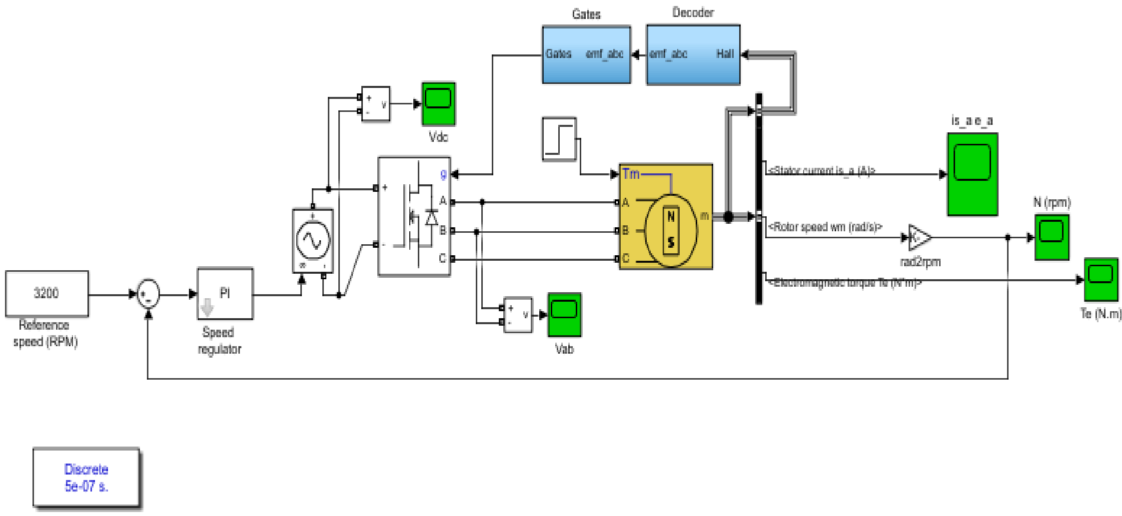

Figure 4.10: Speed control model of brushless dc motor.

According to the reference motor speed, motor speed is controlled by hall sensor, because the figure 4.11, indicate after 0.12 second the rotor maintain its mean speed. The primary goal of motor speed control is to maintain the motor's rotational speed while driving a vehicle at the required speed.

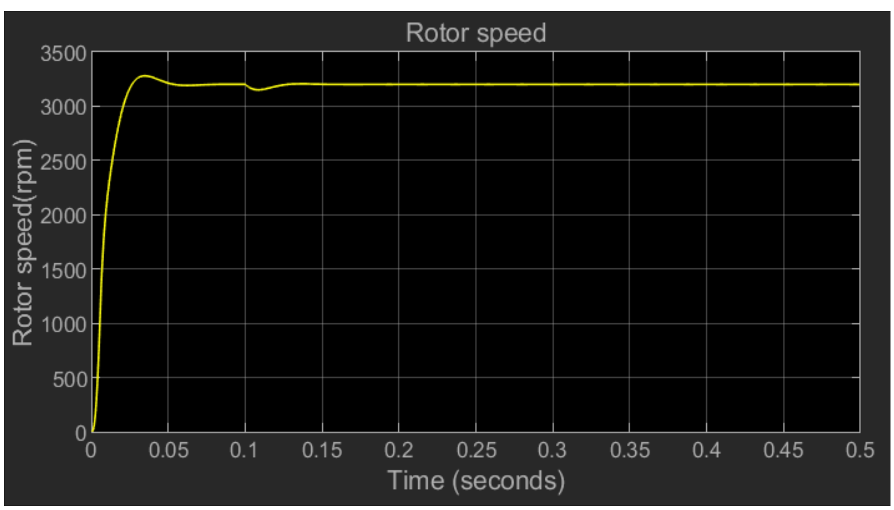

Figure 4. 11: Rotor speed of brushless dc motor.

The phase currents are zero when the vehicle starts to get transient due to the initial phase back e.m.f. Phase currents reach the reference current once the speed reaches the reference speed. As observed in figure 4.11 the rotor speed reaches the reference speed after/at 0.12 second. The stator current also become steady (stable) after 0.12 second. The former controller shows an overshoot in speed response, which is undesirable. The drive takes maximum permissible current to start the motor from standstill.

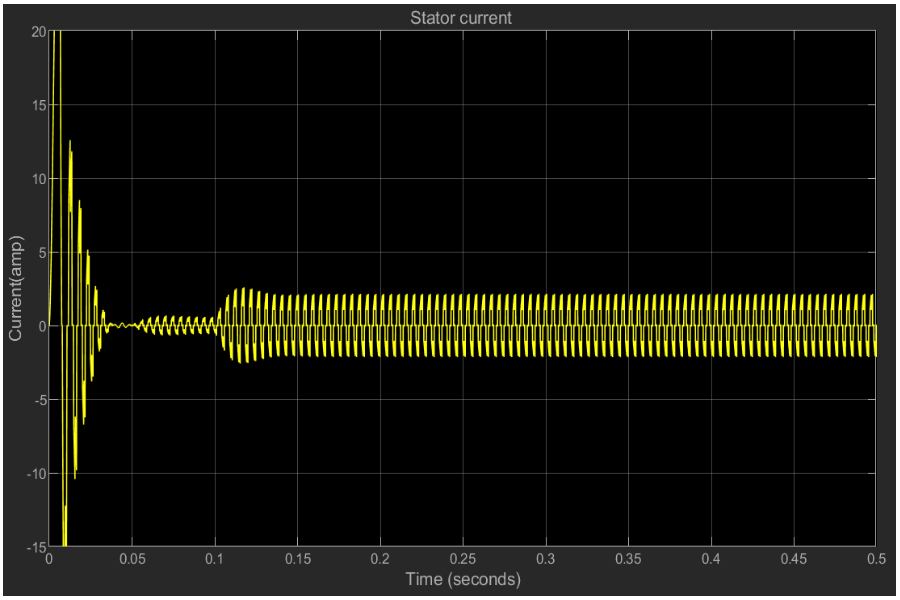

Figure 4.12: Stator current.

The simulation in figure 4.13 indicates, the voltage required to drive this electric vehicle which is below 300 V. Also, the higher driving voltage, the higher the torque and the faster the rotor will rotate. All car manufacturing company is always continuing development to raise the starting voltage special for medium duty vehicle it should. In this vehicle battery which is lithium ion cell, but for the cell 3.7 voltage nominally. But in modules the battery can supply up 350 V. so that when we look the demanded and supplied voltage it is in good condition.

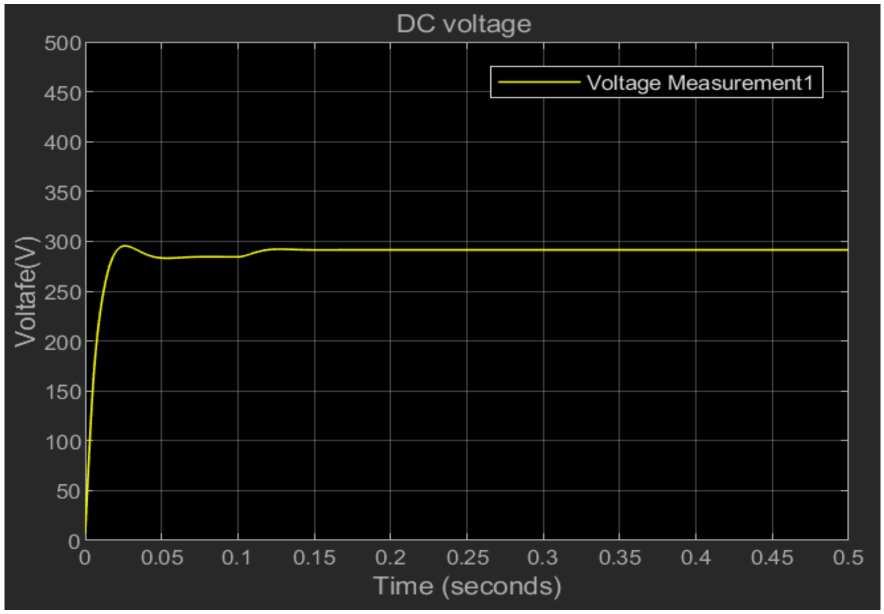

Figure 4.13: Voltage measurement result dc motor.

When a current-carrying conductor is placed in a magnetic field, a force is exerted or it, which produces a torque or twisting moment F x r in rotor. The electromagnetic effect produces this torque, which is why it's termed Electromagnetic torque. In figure 4.14, as discussed in above, electromagnetic torque is excited at start of vehicle up to 0.12 second work of motor. After that electromagnetic torque become stable.

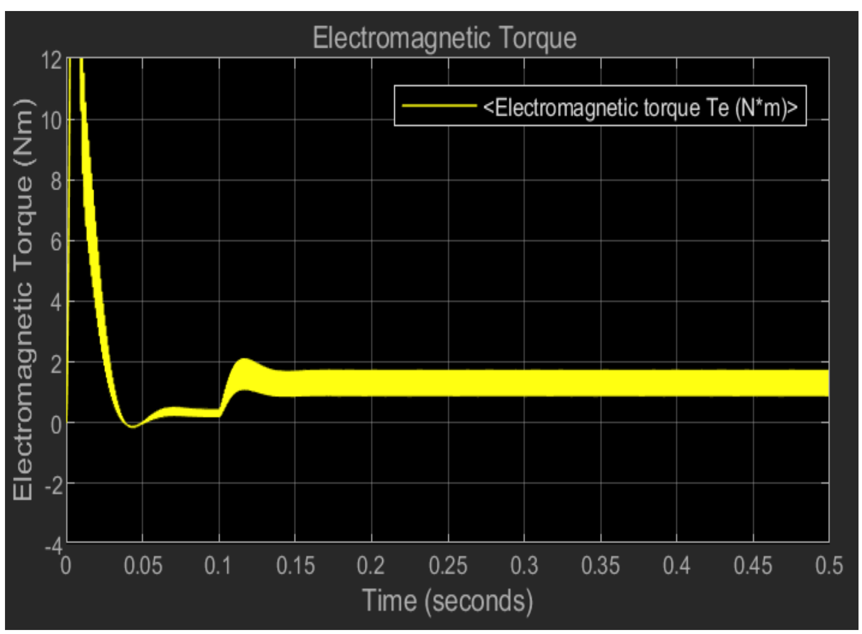

Figure 4.14: Electromagnetic torque result of the simulation.

The Hall Effect is the result of introducing a conductor with current flowing in one direction perpendicular to a magnetic field and getting a measured voltage that is called Hall Effect. Typically, in this electric vehicle motor it is placed on rotor and the stator. The hall sensor fitted on the sensor produce the stator current as figure 4.16.

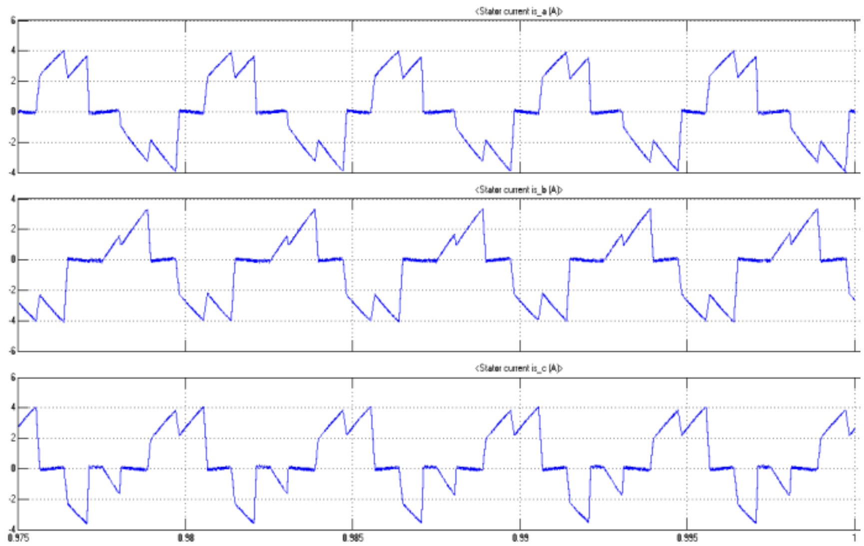

Figure 4.15: Stator currents of three phase motor, adapted from. [81].

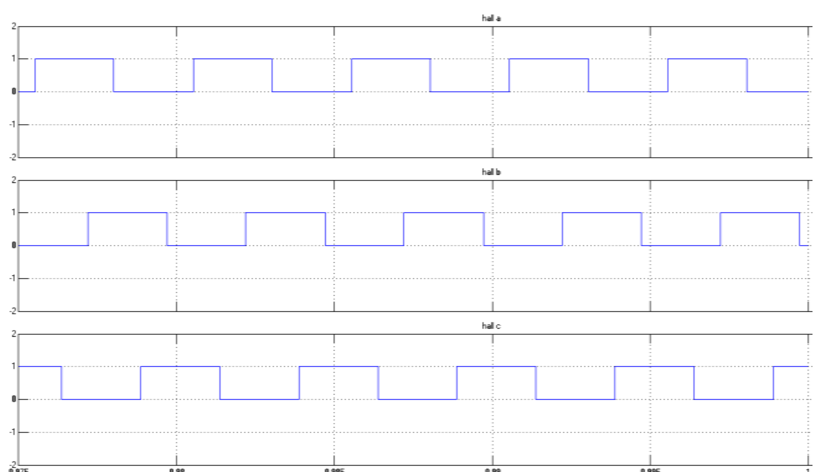

Figure 4.16: Hall sensor outputs of three phase motor, adapted from.[81].

4.1.4 Battery Model

In this part, a model has been worked out which includes the electrochemical battery source block. We can choose any battery predefined in the block, such as Lead Acid, Nibased batteries. In this thesis, lithium-ion battery is considered, due to its scope in modern applications in terms of energy density, lifetime and flat profile of discharge and discharging. The controlled current source block is being used here to account the variation of load. This is being controlled by the current input. In this case, our input current is the result of the varying power requirement by the vehicle during different driving cycles. The table below indicates the data taken for simulating the battery system. The screenshot of the Simulink model is mentioned in the figure 4.17.

Table 4.3: Battery simulation specification

Parameters	Description	Value	Unit
$SOC_{initial}$	Initial state of charge	80	Percent
V(Nominal voltage)	Nominal Voltage per sell	3.7	V
T	Battery response time	1	Sec
R	Resistance	0.1	Ω
C	Capacitance	$1000e^{-6}$	F
L	Inductance	5.76e-4	H
Λ	Amplitude	48	V
R	Internal resistance of the switch	0.01	Ω
R	Internal Diode resistance of Mosfet	0.01	Ω
L	Internal diode inductance	0	H

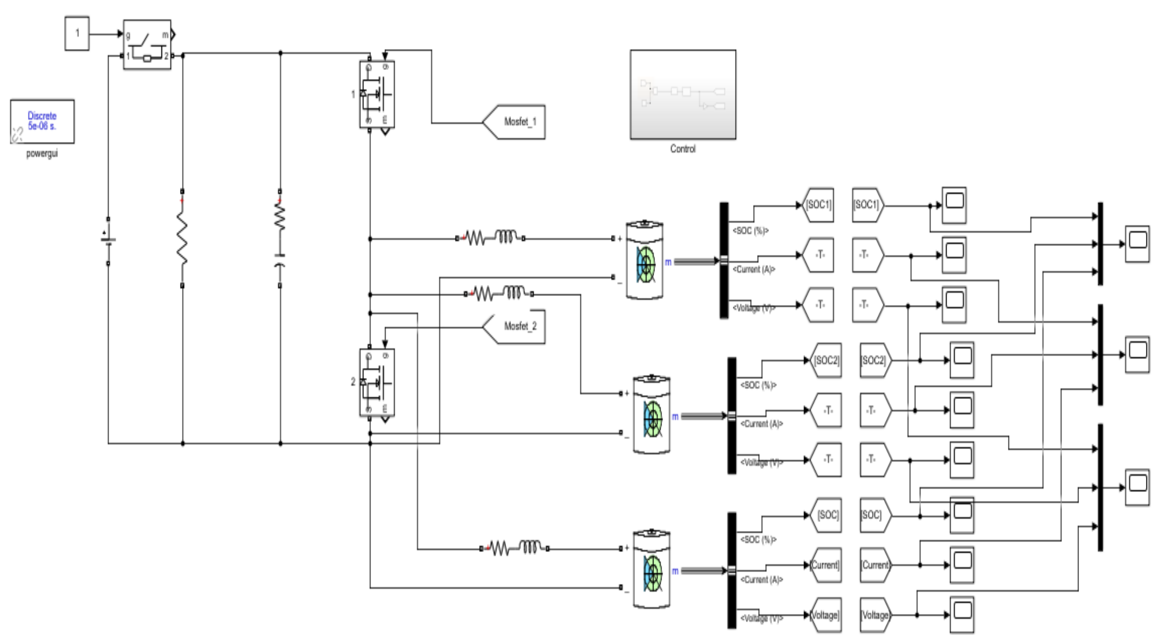

Figure 4. 17: Matlab Simulink for battery model.

Form this section can observe that, energy consumed by the vehicle or State of Charge (SOC) is in discharging mode when GS switch are in OFF mode and energy stored in the battery during charging when GS switch are in ON mode, the battery voltage and current pattern varies in both case i.e. charging and discharging. With these observations can observe that how energy requirement varies with different profile of driving cycle along with the different rated capacity of battery.

4.1.4.1 Case I: In charging mode

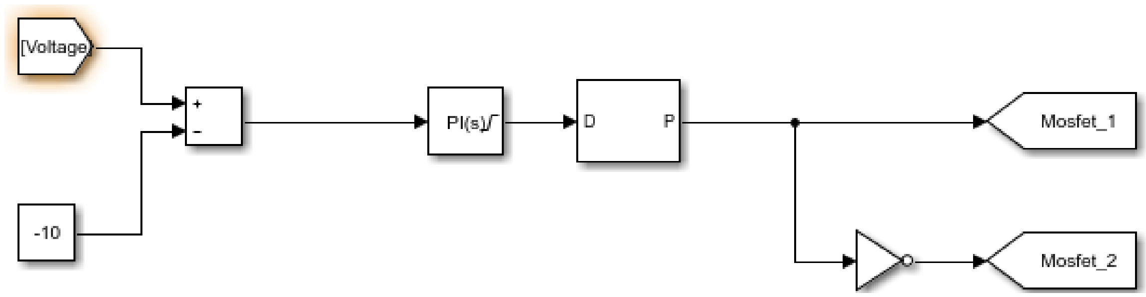

Figure 4.18: Subsystem in charging mode

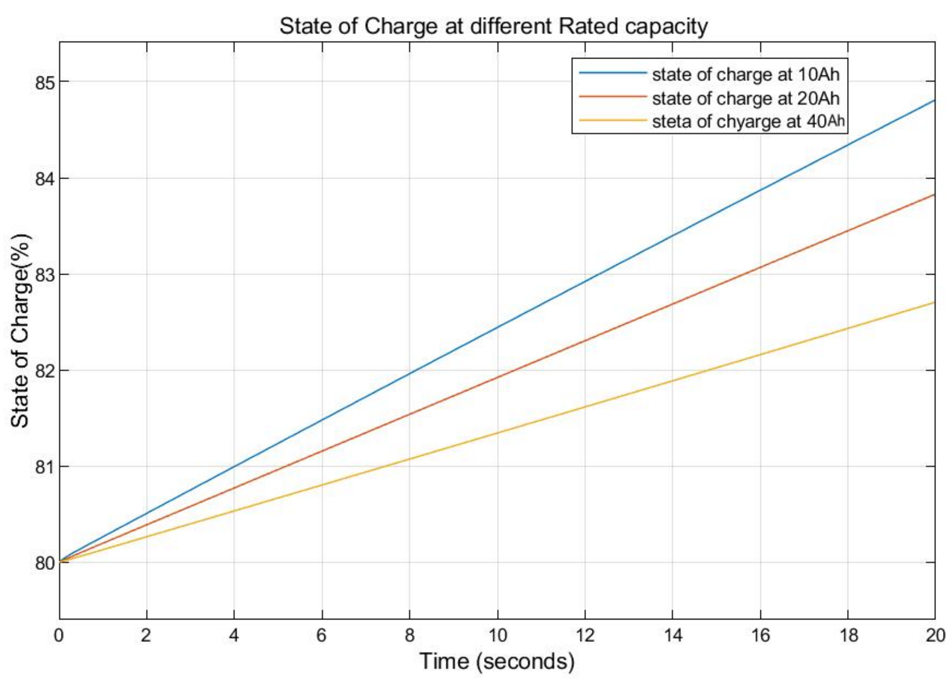

Figure 4.19: Simulation result of battery control model at different Rated capacity (Ah) for state of charge during charging.

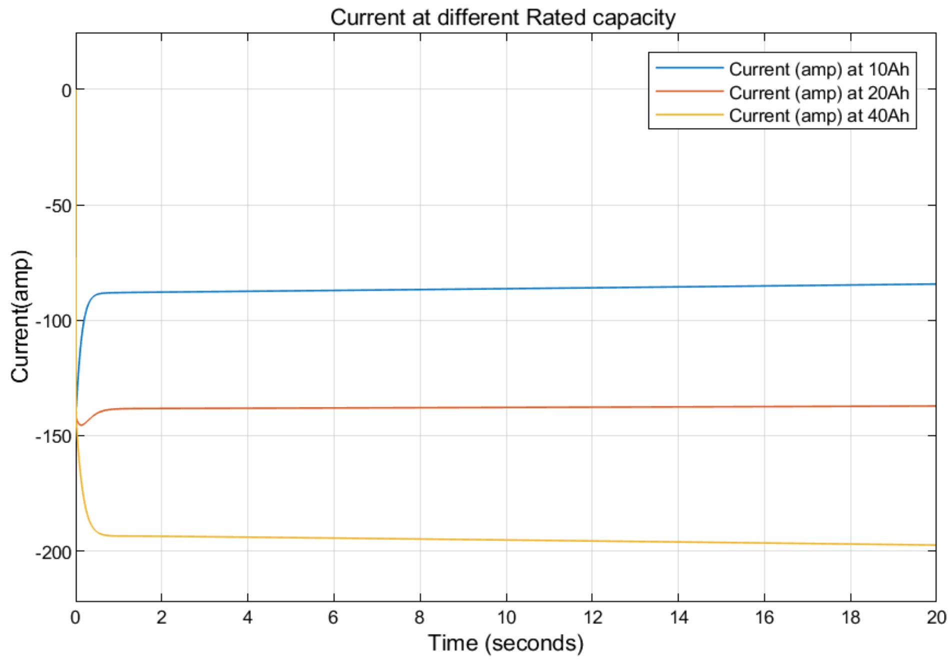

Figure 4.20: Simulation result of battery control model at different Rated capacity (Ah) for current during charging.

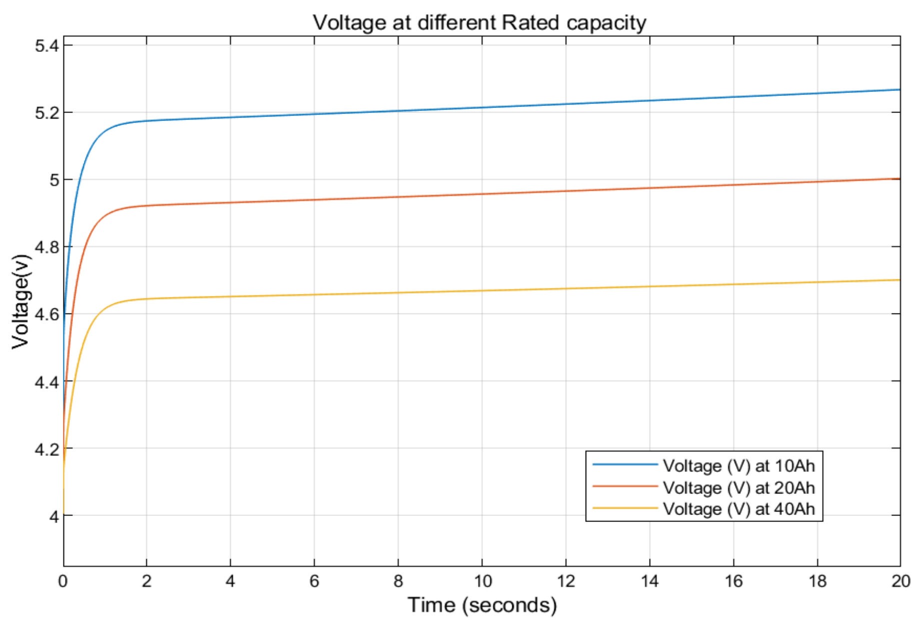

Figure 4. 21: Simulation result of battery control model at different Rated capacity (Ah) for voltage during charging.

4.1.4.2 Case II: Discharging mode

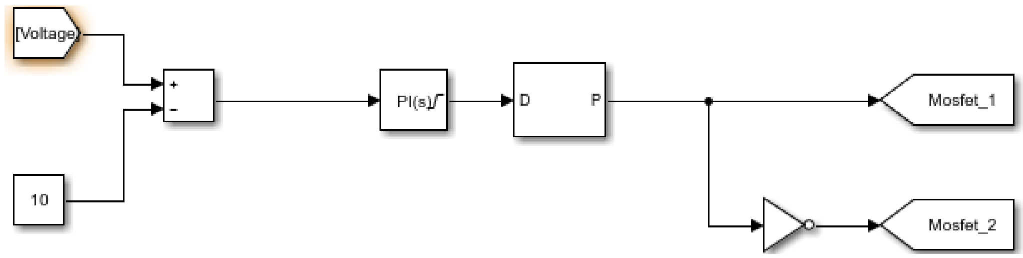

Figure 4.22: Subsystem in discharging

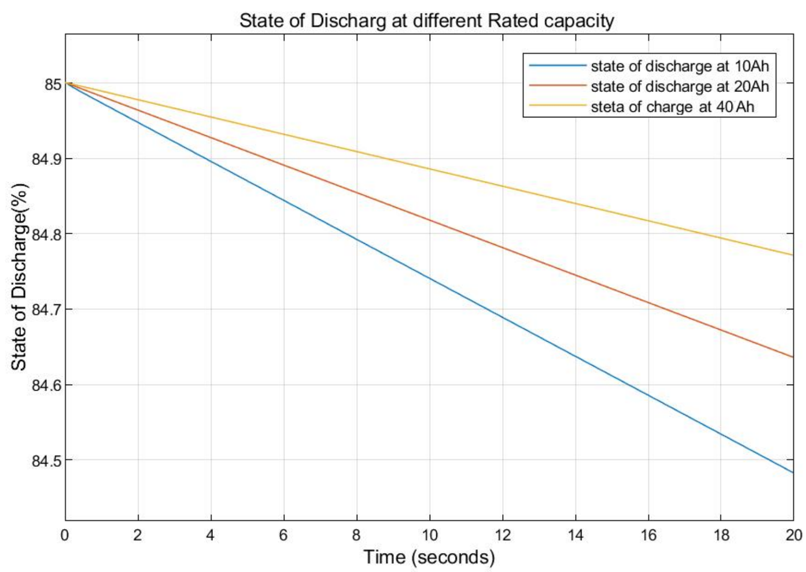

Figure 4.23: State of discharge at different rated capacity.

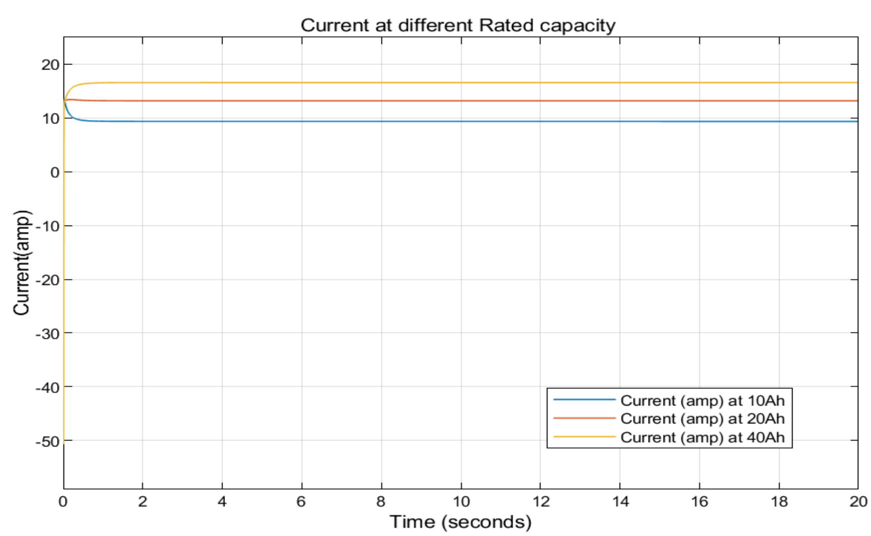

Figure 4.24: Current at different rated capacity.

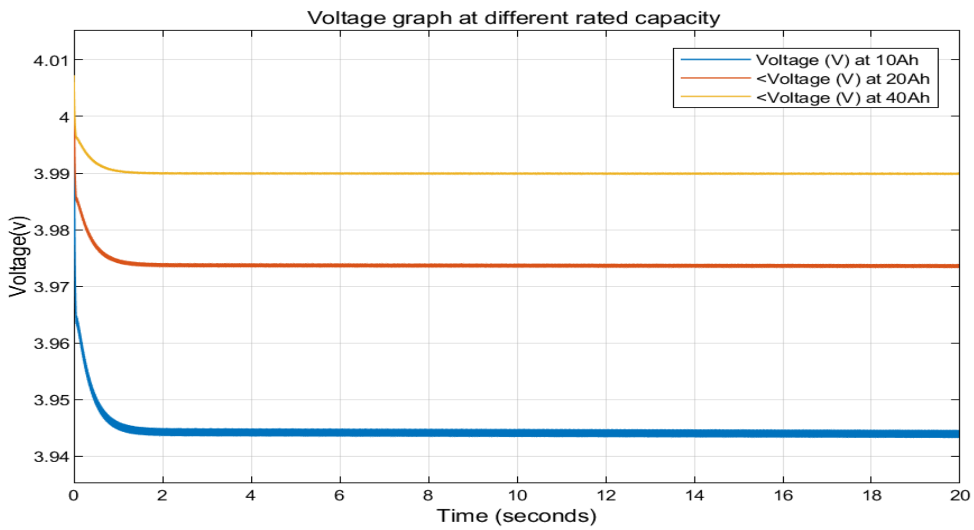

Figure 4.25: Voltage graph at different rated capacity.

Result of the above simulation tabulate as follow:

Table 4.4 Battery simulation result

Case I Charging			
Rated capacity of battery	10Ah	20Ah	40Ah
SOC (%)	84.75	83.85	82.75
Current(amp)	-82	-135	-197
Voltage(v)	5.25	5	4.7
Case II Discharging			
Rated capacity of battery	10Ah	20Ah	40Ah
SOC (%)	84.48	84.68	84.78
Current(amp)	10	13.2	16.3
Voltage(v)	3.944	3.974	3.99

In first case or in charging mode the allowed maximum voltage is 5.25 V, and maximum state of charge is 84.75% and also -82 amp current when the rated capacity of the battery is 10 Ah. While the battery is discharging, the voltage will decrease to 3.944 as a result state of charge also reduces to 84.48% from 85%, and current increase to 10 amp at 10 Ah rated capacity of battery. But the simulation takes long time so that I simulate for 20 sec. As Seen, while the battery is charging, the reference current is decreasing. As a result the charging mode is OK. In discharge mode, the knowledge of the state-of-charge SOC of the battery is a key element in relation with the behavior of the complete system. This quantity actually specifies the level of the energy store that constitutes the battery. The quantity mentioned above needs to be evaluated in order to verify the vehicle can carry out its mission or not.

4.2 Alternator Model

This model demonstrates how the behavior of an alternator can be effectively simulated. Her GS switch is introduced for controlling the grid. And in this model the system response for stator current, stator voltage, rotor speed, and output active power for stability are simulated.

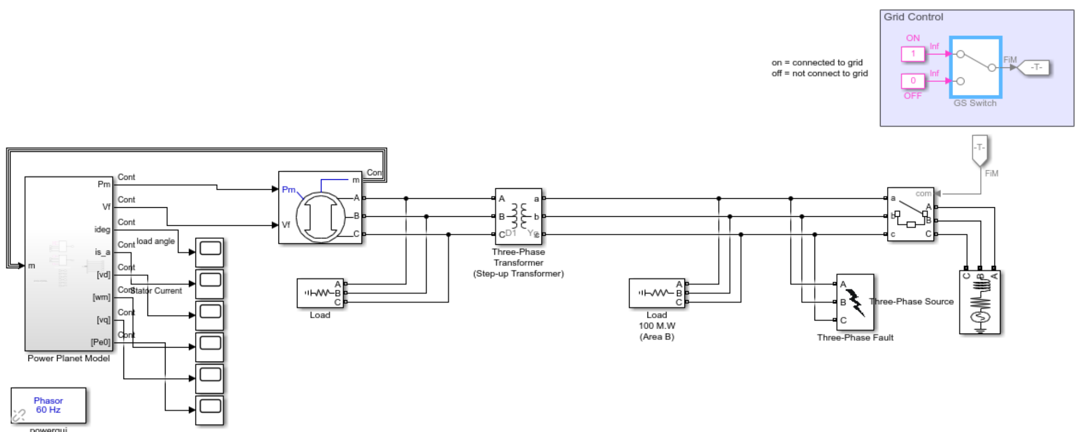

Figure 4.26: Alternator Matlab/Simulink model.

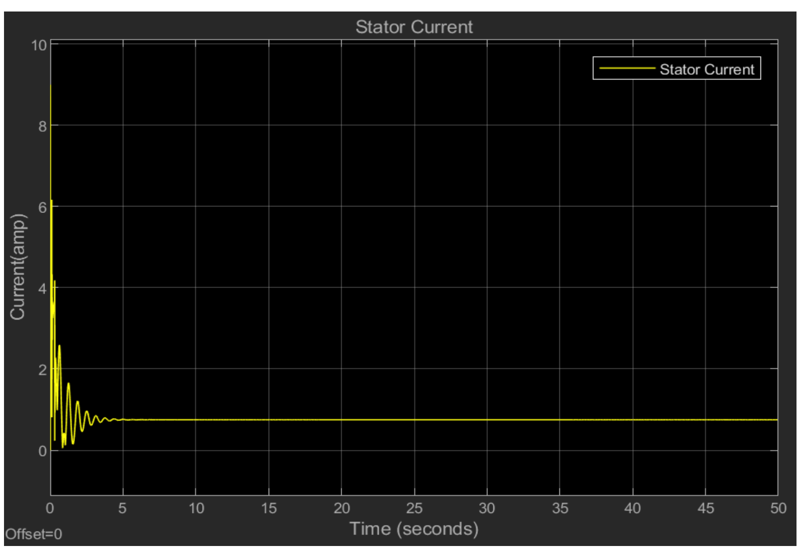

Figure 4.27: Stator current.

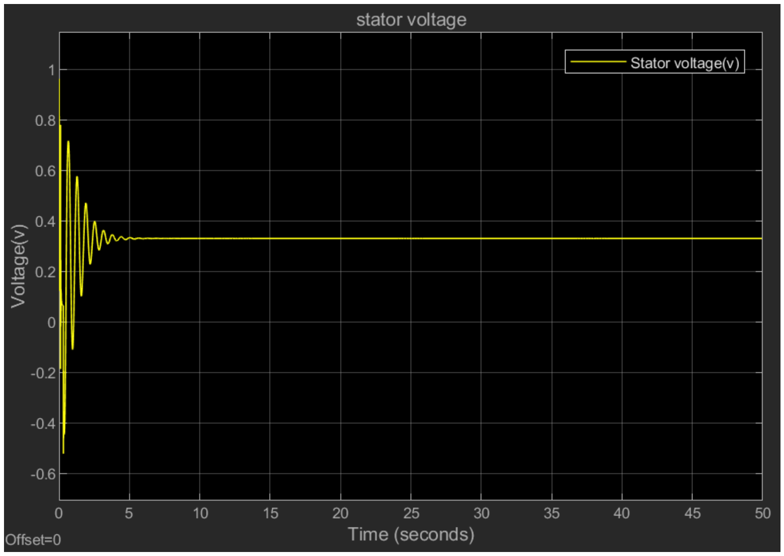

Figure 4.28: Stator Voltage.

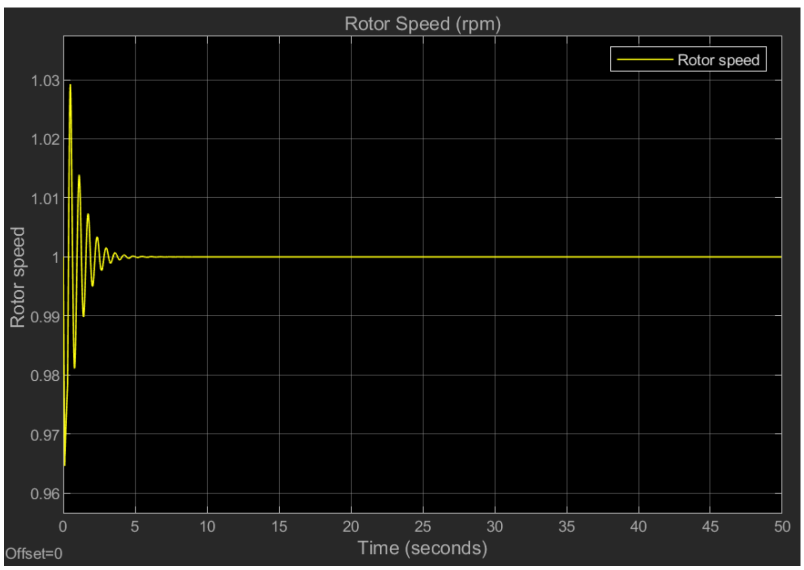

Figure 4. 29: Rotor Speed.

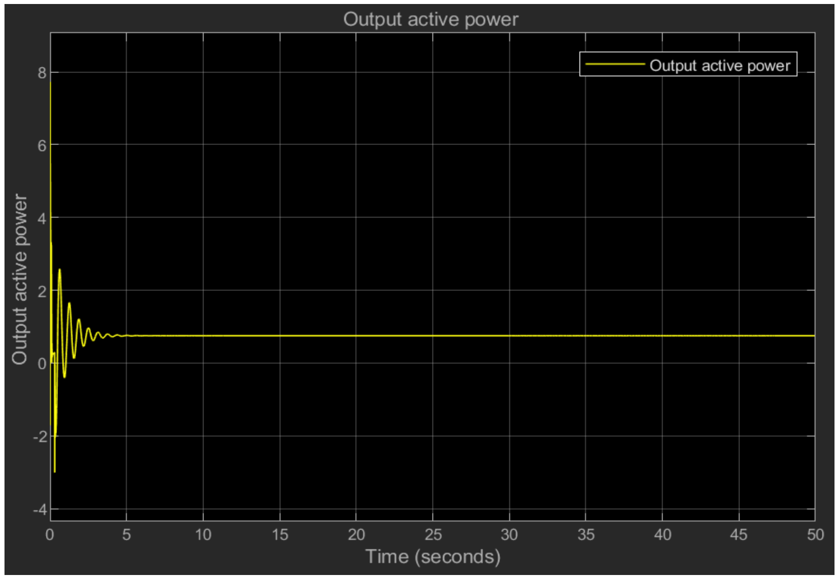

Figure 4.30: Output active power.

In alternator model simulation, the result shows in all case the system become stable in less than five second.

Summery

The author covered some basic information on electric vehicles in this design and analysis project. Furthermore, suitable analytical calculations for electric vehicles under certain driving situations can be found, which are applied in this work by standard and unique driving cycles.

The analytical design for model components, which aided in the creation of each system in two phases and related them, has been succinctly and explicitly presented. Procedures for scenario construction and the operation of software tools have also been briefly explained to the reader. Furthermore, the constraints of these aspects have been discussed, as well as the findings. To cover both the power and energy requirements of vehicle operations, current EV battery packs use a single type of cell.

CHAPTER 5

Conclusions and Recommendation

5.1 Conclusions

Due to the revolution of the transportation industry by electric mobility, this study emphasizes the need of high-performance EV modeling, simulation, and validation. This paper goes over the different types of electric vehicles, their basic parts and structures, energy sources, the different types of motors used in EVs, power conversion, and EV charging. The speed of the electric automobile is considered, as well as the energy required by the battery, battery losses, battery recharge, and alternator power. Alternator detail designs are also described. The block diagram of the system which relate or combine the chassis with the transmission line and their main component and parameter description are included. The energy can be generated utilizing the self-generation concept, and the methods do not pollute the environment. The self-charging system (SCS) was used in this paper, and the driving range of the vehicle was constrained as an optimization problem. The self-charging system was designed with adequate optimization in mechanical energy source and battery charging mechanism in mind. A battery management system is used to control or manage the battery, and this way can extend the battery life of the system. This study is being conducted in order to reduce the power imbalance in the system between energy demand and supply.

And the overall configuration of electric vehicle are simulated in Matlab with different condition. In the battery modeling, the charge and discharge capacity of the cell are evaluated at different rated capacity of the battery. A Matlab/Simulink model of a three phase BLDC motor was developed. The main part of the work was involved in the development of the inverter and its interaction with motor. The aim was to make a model that would be accurate, easy to modify and fast running. It is also observed that the self-charging technology is superior than present electric vehicles in terms of removing the need for time to charge the battery, but beyond that no energy required to drive the vehicle from external source, this leading to the conclusion that self-charging electric vehicles are the vehicles of the future.

Finally, future trends and directions have been evaluated, followed by the findings of this article to synthesize the entire text and provide a clear image of this sector and the areas that require additional research. Modeling and simulation are critical for automobile designers in order to obtain the appropriate torque , demanded and achieved power, battery capacity, battery charge state, and accurate size of the part while minimizing the consumption of electricity are discussed clearly. As per the work of the paper the following point are concluded.

- ❖ The design is performed using mathematical analysis of power requirement, battery capacity and other battery parameter, and alternator. As per the work of this paper the electric vehicle which has gross weight of this 4100 kg designed.
- ❖ The goal of this thesis is to create a self-charging electric vehicle that can deliver cargo weighing up to 2500 kg.
- ❖ To drive this vehicle which has 4100kg, the power requirement is calculated and that is 150 kW.
- ❖ The energy is stored with the help of a battery. For providing sufficient voltage, to electric motor, battery pack is designed with 95 in serious 194 in parallel, totally 18430 cells of battery are required.
- ❖ In order to charge the battery alternator with effective voltage 373.856 V was constructed. The alternator design were confirmed using Matlab/Simulink software, the simulation result for stator current, stator voltage, rotor speed, and output active power show stability of the system.
- ❖ In the simulation result of electric vehicle can observe that the achieved vehicle speed has the same path with input reference vehicle speed (standard driving cycle FTP75 (2474)). From the simulation can observed that yellow curve and blue curve almost follow each other or over laid on the drive cycle speed throughout 2474 seconds.
- ❖ And the paper gives emphasis to the dynamic characteristics of the Lithium-ion battery during various charge and discharge regimes based on different rated capacity of battery. The Simulink result of battery and the parameter are discussed detail. The battery with lower rated capacity (10Ah) can charged fast which mean

can reach 84.75% within 20 second, but also discharging fast. For 40% rated capacity, the battery can store more charge, can utilize for long time. The paper conclude that batteries with higher amp hours deliver more power and more performance.

5.2 Recommendation

Any work in electric vehicle modification is very attentive, very advantageous and challenging. Based on the present time it can be observed that the world population increase which need more electrical power; so that the engineer should deliver more of the power self-power generate system. In self-driving vehicle, a component of one of the power sources may fails, a corrective signal is created in the other power source and causing the motor to be adjusted in power requirement and speed.

5.3 Future Work

The system will be analyzed at high voltage settings in future work connected to this paper. Alternators in vehicles charge batteries; however the rotor of the alternator is mounted on the propeller shaft, resulting in considerable resistance on the induction motor so eliminate this, the propeller shaft should design very carefully. To reach the genuine optimal system design, simultaneous optimization of the several disciplines in a multidisciplinary optimization framework is required. Experimental work or prototype fabrication is required for validating this work.

To achieve high-fidelity cell design optimization, comprehensive micro-structure modeling can be incorporated into the cell model. Because the link between the battery pack design and control parameters is not captured, sequential optimization of the battery pack design followed by an optimal control approach frequently results in non-optimal overall systems. Couple the electrode design parameters, battery structure, and control variables that determine the ideal discharge profiles for distinct cells to perform multi-cell battery pack optimization in a more comprehensive approach than the one given in Chapter 3.

To avoid the optimal battery pack becoming specialized for a specific driving cycle, a multi-point optimal design might be determined using an aggregate objective function, with the optimal solution being the one that performs the best across all driving cycles. Mathematical models, steady state models, multi-physics domain, vehicle dynamics, and transient modeling are a vital objective in electric vehicle.

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APPENDIX A:

Ambient Temperature block represent an ideal energy source in a thermal network that can maintain a controlled temperature difference regardless of the heat flow rate. The temperature difference is set by the physical signal port S. A positive temperature difference causes the temperature at port B to be greater than the temperature at point A.

Gear Box block represent an ideal, non-planetary, fixed gear ratio gear box. The gear box is characterized by its only parameter, gear ratio, which can be positive or negative. Connection S and O are mechanical rotational conserving ports associated with the box input and output shaft, respectively.

Simplified PMDC motor drive model description

The permanent-magnet synchronous machine (PMSM) drive is one of best choices for a full range of motion control applications. In this block represent a servomotor and drive electronics operation in torque control mode, or equivalent current control mode. The motor permissible range of torque and speeds is defined by a torque- speed envelope, and the output torque is assumed to track the torque reference demand Tr with time constant Tc.

The servomotor block should be connected to a DC supply. If modelling losses using the single efficient measurement option electrical losses are assumed to be the sum of constant term plus two additional terms that are proportional to the square of the torque and the square of speed respectively. For all losses modelling options, the supply series resistance is not included as part of the efficient calculation. The block produce a positive torque acting the mechanical C to R ports.

In heat exchanger block, the block Pipe (Pipe TL) is a model pipe flow dynamic in a thermal liquid network due to viscous friction losses and convective heat transfer between the liquid and pipe wall. The effects of dynamic compressibility and fluid inertia can be optionally included.

The pipe contain a constant volume of liquid. Temperature evolves based on the thermal capacity of this liquid volume. Setting fluid dynamic compressibility to ON also cause’s pressure to evolve based on the dynamic compressibility of the liquid volume. Setting fluid inertia to ON cause the liquid to resist acceleration. Port A and B are thermal liquid conserving ports associated with the pipe inlet and outlet. Port H is the thermal conserving port associate with the pipe wall.

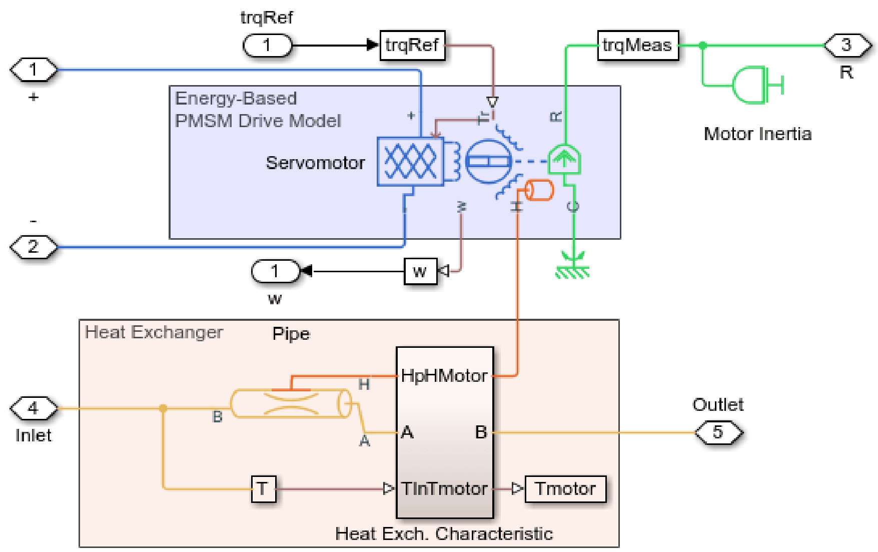

Figure a. PMDC motor drive model.

Heat exchangers block description:

Mass and Energy Flow rate Sensor (TL) this block measure mass and energy flow rates in a thermal liquid network. There is no change in pressure or temperature across the sensor. The physical signal port M[kg/s] and Phi[w] report the mass flow rate and the energy flow rate, respectively, through the sensor. The positive flow direction is from port A and B.

Heat flow source block represent an ideal energy source in a thermal network that can maintain a controlled heat flow rate regardless of the temperature difference. The heat flow rate is set by the physical signal port S. A positive heat flow form port A to port B.

Temperature Sensor this block measures temperature in a thermal network. There is no heat flow through the sensor. The physical signal port T reports the temperature difference across the sensor. The measurement is positive when the temperature at port A is greater than the temperature at port B.

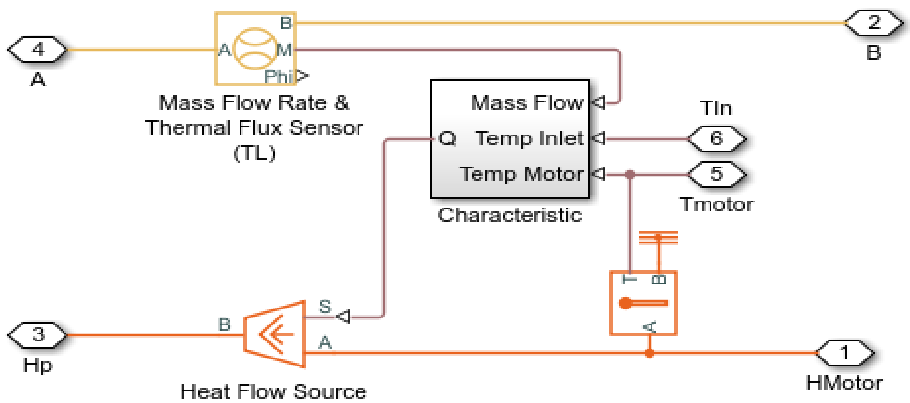

Figure b. Heat exchanger block.

Characteristics block

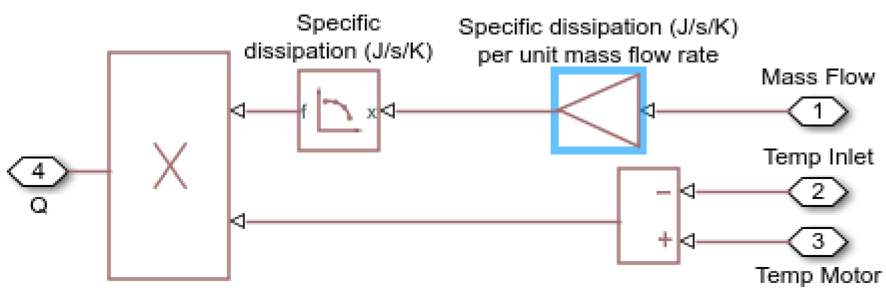

Figure c. Characteristics subsystem model.

Cooling System Subsystem description:

In radiator there is hose radiator block represent dynamic in a thermal liquid network due to viscous friction losses and convective heat transfer between the liquid and pipe wall. The effects of dynamic compressibility and fluid inertia can be optionally included.

The pipe contain a constant volume of liquid. Temperature evolves based on the thermal capacity of this liquid volume. Setting fluid dynamic compressibility to ON also cause's pressure to evolve based on the dynamic compressibility of the liquid volume. Setting fluid inertia to ON cause the liquid to resist acceleration. Port A and B are thermal liquid conserving ports associated with the pipe inlet and outlet. Port H is the thermal conserving port associate with the pipe wall.

Thermal liquid setting (PL) block provides liquid properties to the connecting thermal liquid network. The liquid properties can be specified as two- dimensional table or one dimensional vectors. For the two dimensional liquid property table, rows correspond to temperature vector and columns correspond to pressure vector. The one dimensional liquid property vectors correspond to temperature vector. The default liquid is water.

Expansion Tank block this block models an interface between a thermal liquid network and a mechanical network. It can be used as a building block for liner actuators.

The convertor contain a variable volume of liquid. Temperature evolves based on the thermal capacity of this liquid volume. Setting fluid dynamic compressibility to ON also causes pressure to evolve based on the dynamic compressibility of the liquid volume. If mechanical orientation is set to positive or negative, than an increase in the liquid volume corresponding to a positive or negative displacement, respectively, of port R relative to port C.

Port A is the thermal liquid conserving port associate with the convertor inlet. Port H is the thermal conserving port associated with the thermal mass of the liquid volume. Ports R and C are the mechanical translation conserving ports associated with the moving interface and the converter casing, respectively.

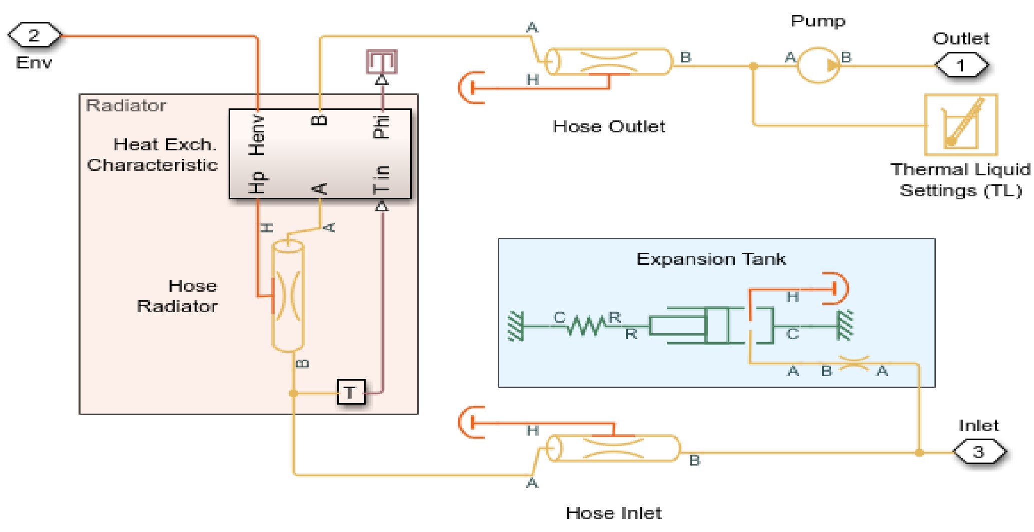

Figure d. Cooling System Subsystem model.

Vehicle Control Subsystem description

In this block there is three main block again, those are torque demand management, cruise control and feed forward form for regenerative braking. In torque demand management block maximum torque demanded, force for maximum pedal deflation and torque per unit brake pedal force are imported.

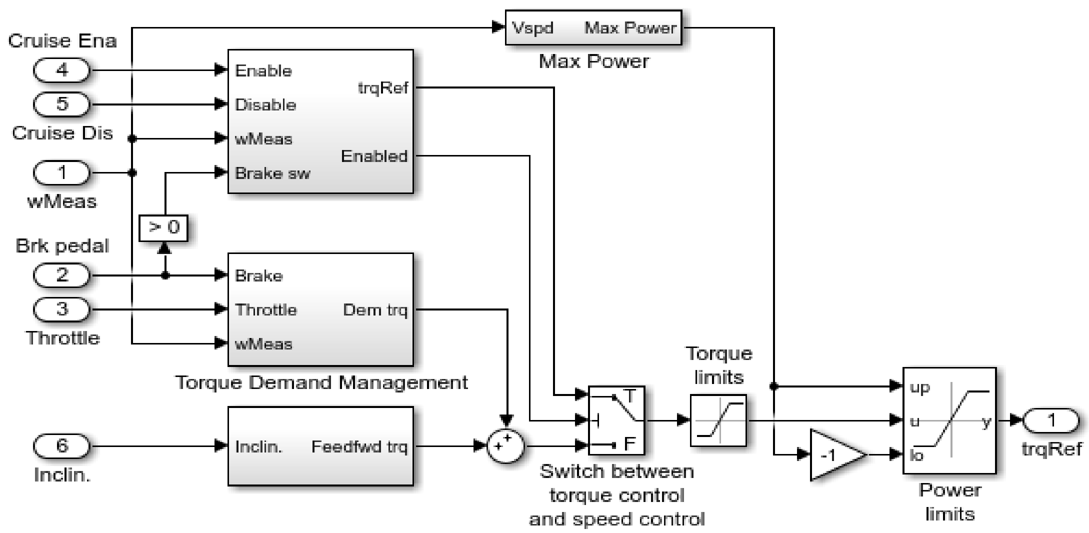

Figure e. Vehicle Control Subsystem model

Vehicle dynamics subsystem description

Force source block represent an ideal source of that generates force proportional to the input physical signal. Block connection R and C are mechanical translation conserving ports. Port S is the physical signal port, through which control signal that drives the source is applied. Positive signal at port S generates force acting C to R.

Wheel and Axle block represent the wheel and axle mechanism as an ideal convertor between mechanical rotational and mechanical translation motions. The mechanism has two connection: port A correspond to the axle and is a mechanical rotational conserving port; port P correspond to the wheel periphery and is a mechanical translational conserving port.

Vehicle Mass block represent an ideal mechanical translation mass.

Air, Gra, Rol and Acc subsystem block air resistance, gradient resistance, rolling resistance and acceleration are introduced.

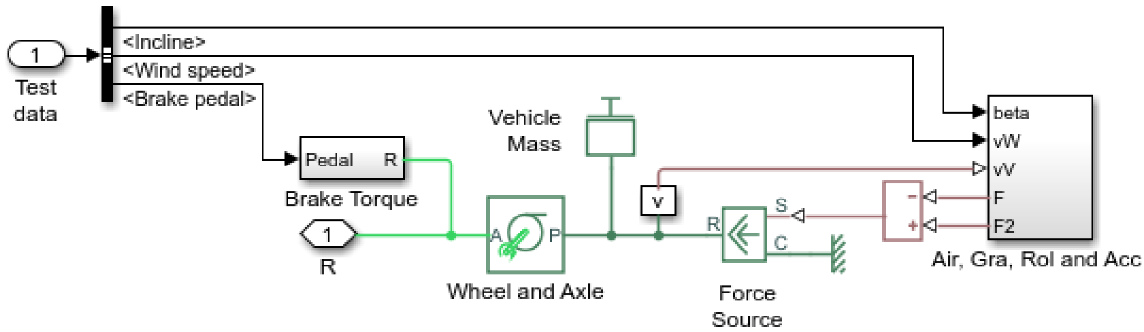

Figure f. Vehicle dynamics subsyatem model.

Appendix B

Electric vehicle model

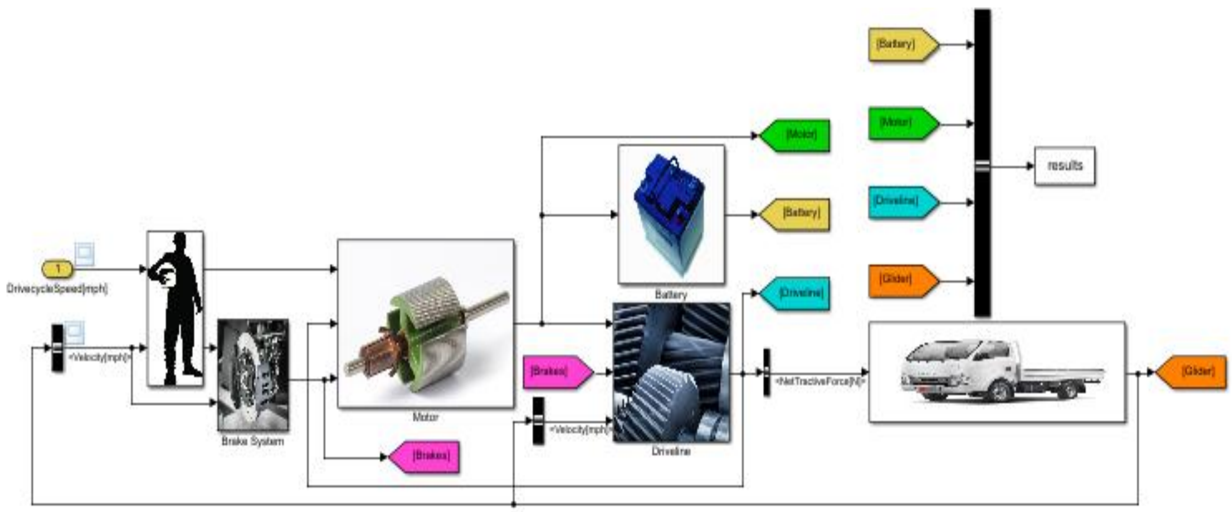

Figure g. Electric vehicle model.

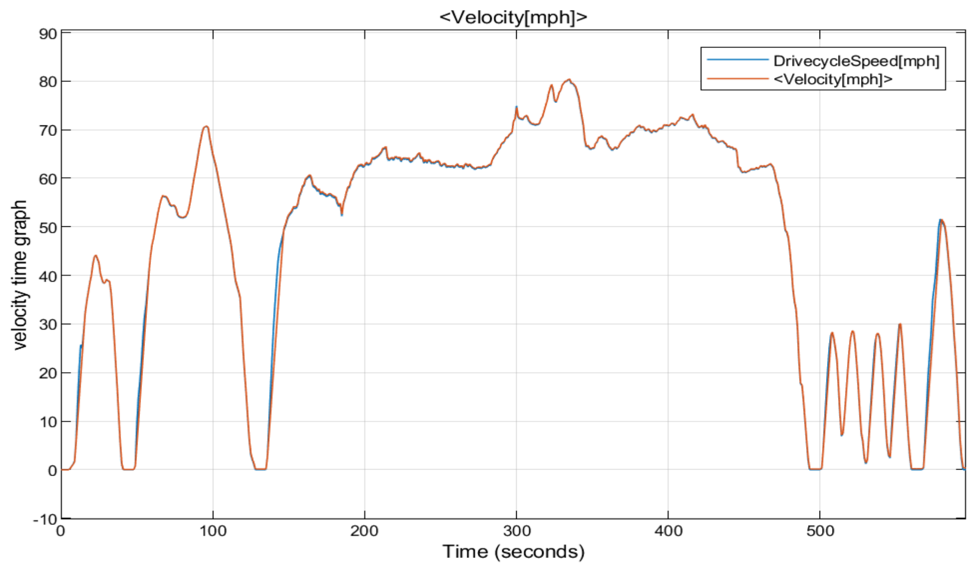

Figure h. Validation result of drivcycle.(from above model result).

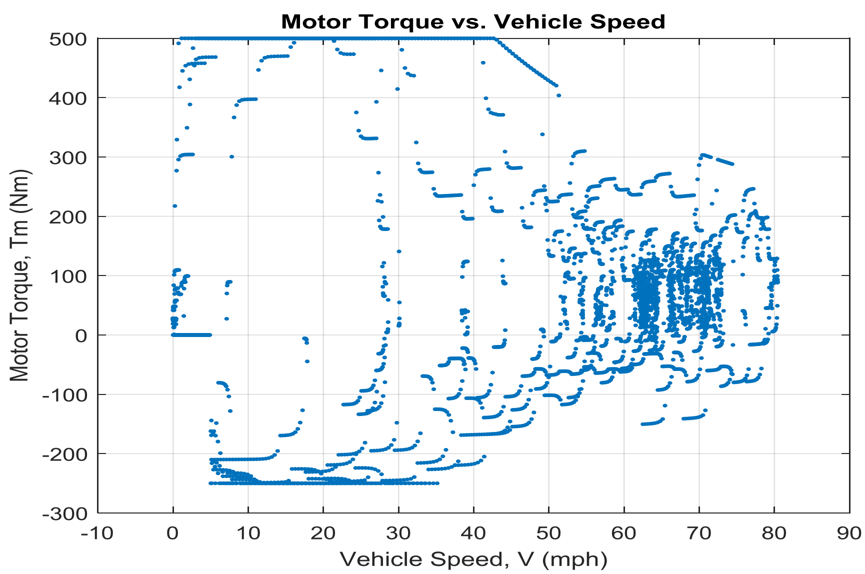

Figure i. Motor torque vs vehicle speed

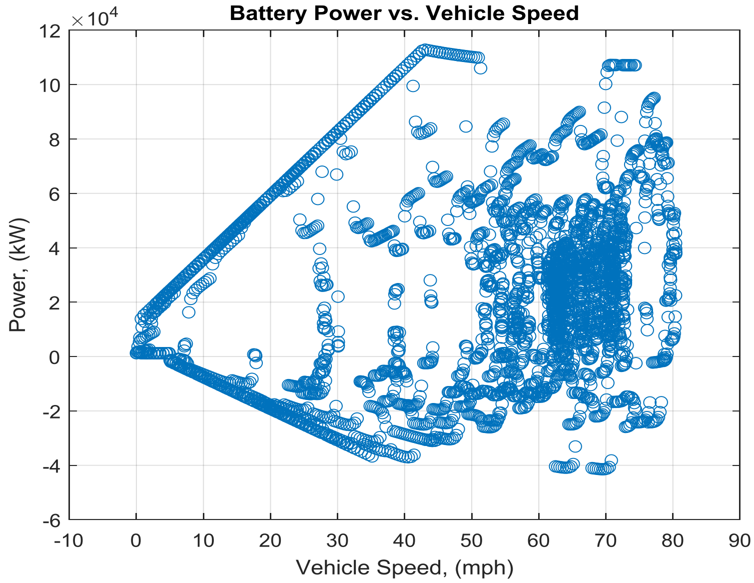

Figure j. Battery power vs vehicle speed

APPENDIX C

Motor speed control Decoder and Gates subsystem

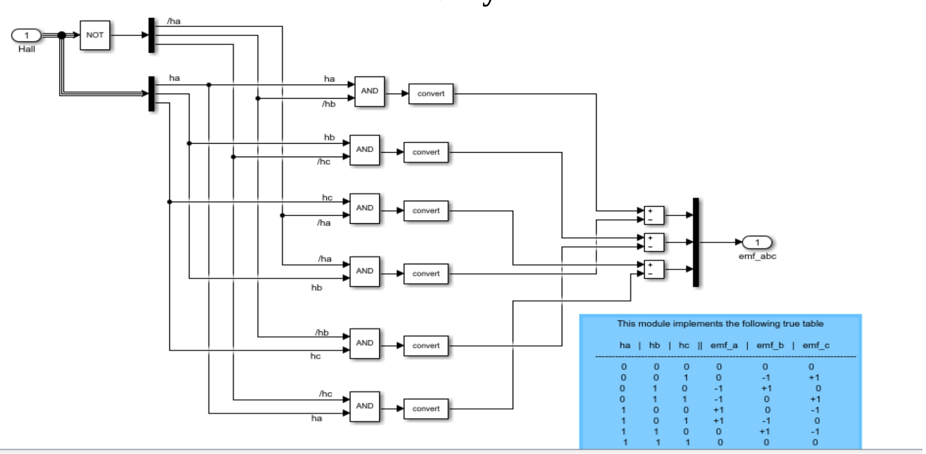

Figure k. Motor speed control decoder code and model

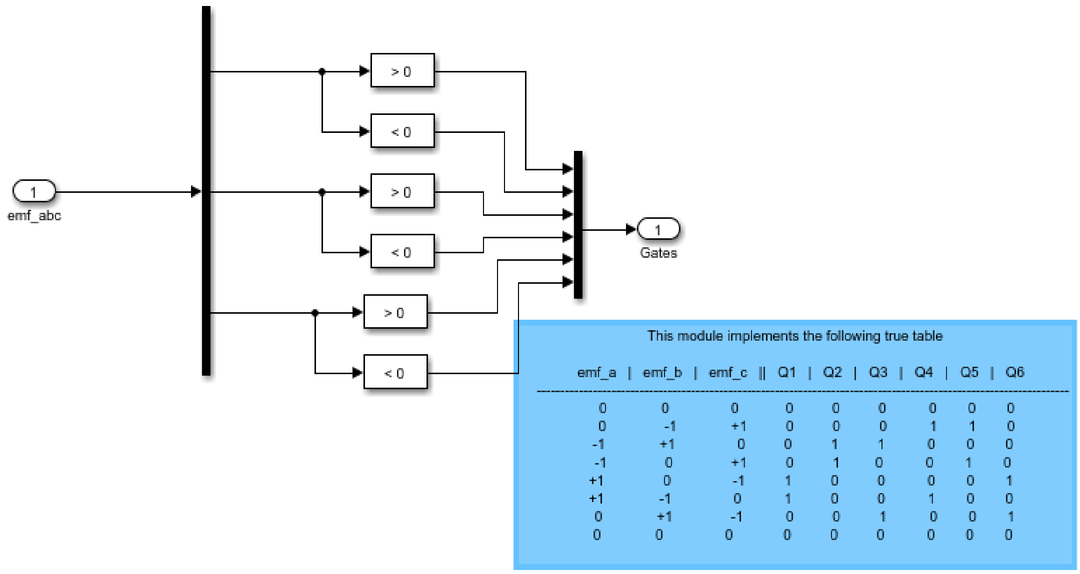

Figure 1. motor speed control gates subsystem

Appendix D:

Table a. Specifications (8-stack models) permanent magnet brushless dc motors:

	EMS-075Q8016	EMS-075Q8064	EMS-075R8017	EMS-075R8018	EMS-075G8017	EMS-075G8018
	Low Speed	High Speed	Low Speed	High Speed	Low Speed	High Speed
DC Input Voltage [VDC ± 15%]	12		24		48	
Rated Cont. Torque [Nm (oz-in)]	0.67 (95)	0.35 (50)	0.78 (110)	0.49 (70)	0.85 (120)	0.74 (105)
Peak Torque [Nm (oz-in)][(1)]	1.27 (180)	0.64 (90)	1.83 (260)	1.13 (160)	2.19 (310)	2.40 (340)
Rated Speed [RPM]	1300	2950	1700	3000	1900	3000
No-load Speed [RPM]	1700	3400	2150	3400	2250	3450
Rated Cont. Power [W (HP)][(2)]	90 (0.12)	110 (0.15)	140 (0.19)	160 (0.21)	180 (0.24)	245 (0.33)
DC Input Current [ADC]	12.1	13.6	8.6	9.3	5.0	6.6
Power Derating Above 23°C [W/°C (W/°F)]	0.51 (0.28)	1.47 (0.82)	0.92 (0.51)	2.04 (1.14)	1.88 (1.05)	1.82 (1.01)
Motor Rotor Inertia [E-5 kg-m² (oz-in-sec²)]	3.35 (0.0048)					
Weight [kg (lb)]	1.41 (3.10)					
Available Control Modes	Open-loop speed control "OLV" mode (standard), current mode, and velocity mode					
Amplifier Type	PWM (20 kHz) 4-quadrant control					
Current (Torque) Loop Type	DQ PI, 100 μs update time					
Velocity Loop	PID / PDF 200 μs update time					
Standard Analog Input	0 to +10.0 VDC, 10kΩ, 12-bit resolution					
Standard Digital I/O	• Reverse direction input: +3 to +60 V (high); 0 to +0.5 V (low) at 3 mA nominal draw, sourcing • Speed/status output: open collector, +60 V max., 100 mA max. sink					
Speed / Status Output	• Speed monitor: 9 pulses per motor revolution • Drive over-temperature fault: 25% duty-cycle at 10 Hz • Bus under-voltage or over-voltage fault: 50% duty-cycle at 10 Hz • Stall or short-circuit fault: 75% duty cycle at 10 Hz				• Other fault: 100% duty cycle • Disabled: 0 V (nominal) output • Externally visible status LED notifies user of motor condition	
Standard Protection Features	• I²T current foldback • Over-voltage detection[(3)] • Short-circuit protect		• Reverse polarity protect • Load dump protect • Drive over-temperature protect		• IP50 protection level • Locked rotor protect (disable after three failed start attempts)	
Optional Drive Configuration Features (Contact Allied Motion for Details)	• Customized analog command input voltage ranges • Motor winding over-temperature protect		• Sinking and sourcing inputs • Separate motor-enable input • IP65 protect level • 2-wire input		• PWM speed control • Non-isolated, J1939 CAN input[(4)] • Potentiometer speed control • And more...	
Ambient Storage Temperature	-40 to 125 °C (-40 to 257 °F)					

Appendix: E

Alternator model in off mode.

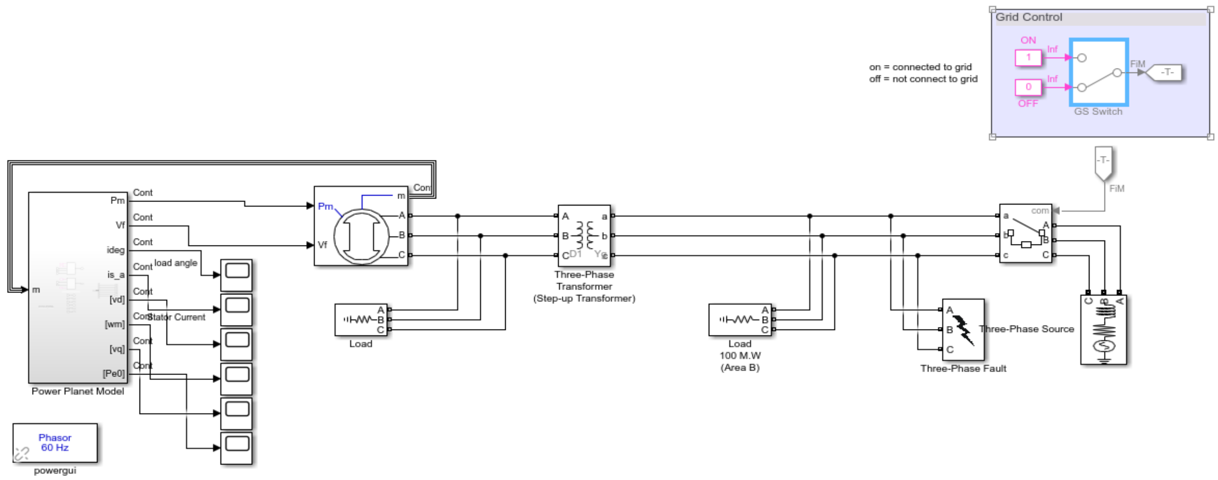

Figure m. Alternator model during discharge.

Subsystem of the alternator model

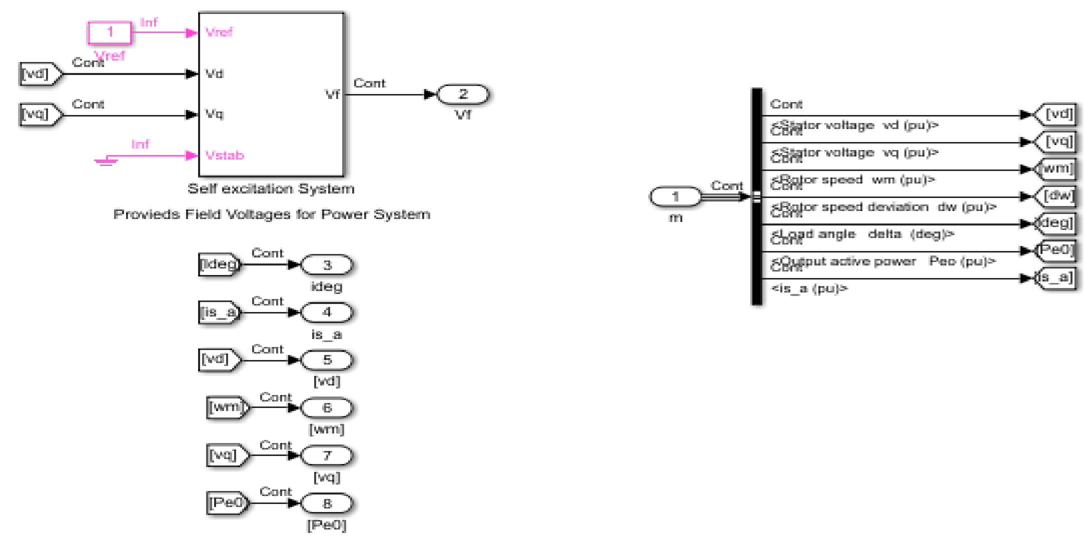

Figure n. Alternator subsystem model.

Appendix F

Modeling of three phase invertor sub system.

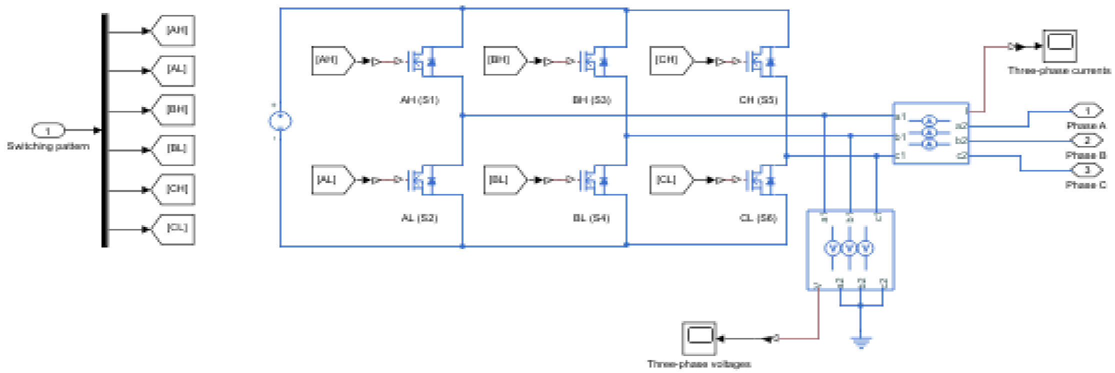

Figure o. Three phase invertor subsystem model