Design and Simulation of Transmission System for Hybrid Electric Bajaj Quet

By

Surafel Kebede Argaw

A Thesis Submitted to

Mechanical System and Vehicle Engineering Program

School of Mechanical, Chemical and Materials Engineering

Presented in partial fulfillment of the requirement for the degree of

Master of Science in Automotive Engineering

Office of Graduate Studies

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DECLARATION

I, the under signed, declare that this thesis entitled **"Design and Simulation of Transmission system for hybrid electric Bajaj Quet"** is my original work, and has not been presented by any other person for an award of a degree in this or any other University.

Surafel Kebede ______________________ ______________

Student Name Signature Date

This thesis work has been submitted for examination with my approval as university supervisor.

Ramesh Babu Nallamothu ______________ ______________

Advisor Name Signature Date

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ACRONYMS

AC	Alternating Current
ADVISOR	Advanced Vehicle Simulator
EFCM	Equivalent Fuel Consumption
EPA	Environmental Protection Agency
EV	Electric Vehicle
FC	Fuel Cell
HEV	Hybrid Electric Vehicle
ISG	Integrated Starter Generator
PHEV	Plug-in Hybrid Electric Vehicle
PEACS	Parallel Electric Assist Control Strategy

ABSTRACT

Hybrid vehicles use both a renewable electric power and a nonrenewable gasoline fuel to drive the wheel. This enables them to use less gasoline than conventional gasoline vehicles, they also contribute less emission of greenhouse gas. Hybrid electric vehicles also allows a smaller more efficient engine to be used, most of them utilize the concept of regenerative breaking for optimized utilization of energy. The main objective of this thesis is to model and simulate a transmission system for four-wheel hybrid electric bajaj by using MATLAB/Simulink. Initially the model of components was created by using MATLAB/Simulink and the full vehicle system model was created.

In this paper a conventional Bajaj Quet and hybrid Bajaj Quet model was developed by using MATLAB/Simulink environment. The model was created to investigate the speed and fuel consumption variation or difference. Individual parts like battery, motor DC/DC convertors, regenerative braking systems are modeled and analyzed. From the simulation it is observed that the hybrid vehicle shows great advantage over the conventional.

Key words: Hybrid Bajaj; DC motor; Battery; IC engine; DC/DC convertor

CHAPTER ONE
INTRODUCTION

1.1 Motivation

The 21st century modern culture and advancement of technology brought along an increasing global warming and an irreversible climate change. It is an obvious fact that earth's climate is transformed, proven by the frequent sever storm, the drastic shrinking of polar ice caps and mountain glaciers, the increased amount of flooding in coastal areas, and longer droughts in arid section of the world. There are longer droughts in arid section of the world. There are large holes in the ozone layer of the earth's atmosphere and smog levels are ever increasing leading to decreased air quality M. Beliveau et al., (2010).

Countries around the world are working to drastically reduce CO_2 emissions as well as other harmful environmental pollutants. Everything from cars and industries to livestock and crops are being studied and regulated with plans of minimizing pollution levels

Amongst the most notable producers of these pollutants are automobiles, which are almost exclusively powered by internal combustion engines and spew out unhealthy emissions. Cars and trucks are responsible for almost 25% of CO_2 emission, and other major transportation methods account for another 12% M. Beliveau et al., (2010).

For this big concern of the world hybrid electric vehicle (HEV) is the best solution. Hybrid electric vehicle add an electric power path to the conventional power train which help to improve fuel economy by engine downsizing load leveling and regenerative braking.

1.2 Background

The definition available for hybrid vehicle is so general that it anticipates future technologies of energy sources. The term hybrid vehicle refers to a vehicle with at least two sources of power. A hybrid-electric vehicle indicates that one source of power is provided by an electric motor. The other source of motive power can come from a number of different technologies, but is typically provided by an internal combustion engine designed to run on either gasoline or diesel fuel. As proposed by Technical Committee (Electric Road Vehicles) of the International Electrotechnical Commission, an HEV is a vehicle in which propulsion energy is available from two or more types of energy sources and at least one of them can deliver electrical energy M. Ehsani (2005). Based on this general definition, there are many types of HEVs, such as:

- The gasoline ICE and battery
- Diesel ICE and battery

Most commonly, the propulsion force in HEV is provided by a combination of electric motor and an ICE. The electric motor is used to improve the energy efficiency (improves fuel consumption) and vehicular emissions while the ICE provides extended range capability M. Ehsani (2005).

Energy use in Conventional vs Hybrid Vehicle

Conventional Vehicle

Energy consumption in conventional vehicle

- In order to maintain movement, vehicles must produce power at the wheels to overcome:
    - Aerodynamic drag
    - Rolling resistance
    - resistive gravity forces associated with climbing a grade
- Further, to accelerate, the vehicle must overcome its inertia. Most of the energy expended in acceleration is then lost as heat in the brakes when the vehicle is brought to a stop.
- The vehicle must provide power for accessories such as heating fan, lights, power steering, and air conditioning
- Finally, a vehicle will need to be capable of delivering power for acceleration with very little delay when the driver depresses the accelerator, which may necessitate keeping the power source in a standby (energy-using) mode M. Ehsani (2005).

Much of the heat generated by combustion cannot be used for work and is wasted, both because heat engines have theoretical efficiency limit. Moreover, it is impossible to reach the theoretical efficiency limit because:

1. Some heat is lost through cylinder walls before it can do work
2. Some fuel is burned at less than the highest possible pressure
3. Fuel is also burned while the engine is experiencing negative load (during braking) or when the vehicle is coasting or at a stop, with the engine idling.

The Figure 1 below shows the translation of fuel energy into work at the wheels for a typical midsize vehicle in urban and highway driving. As it is shown there is a loss associated only to the conventional vehicles only such as standby idle, accessories, driveline, and braking losses.

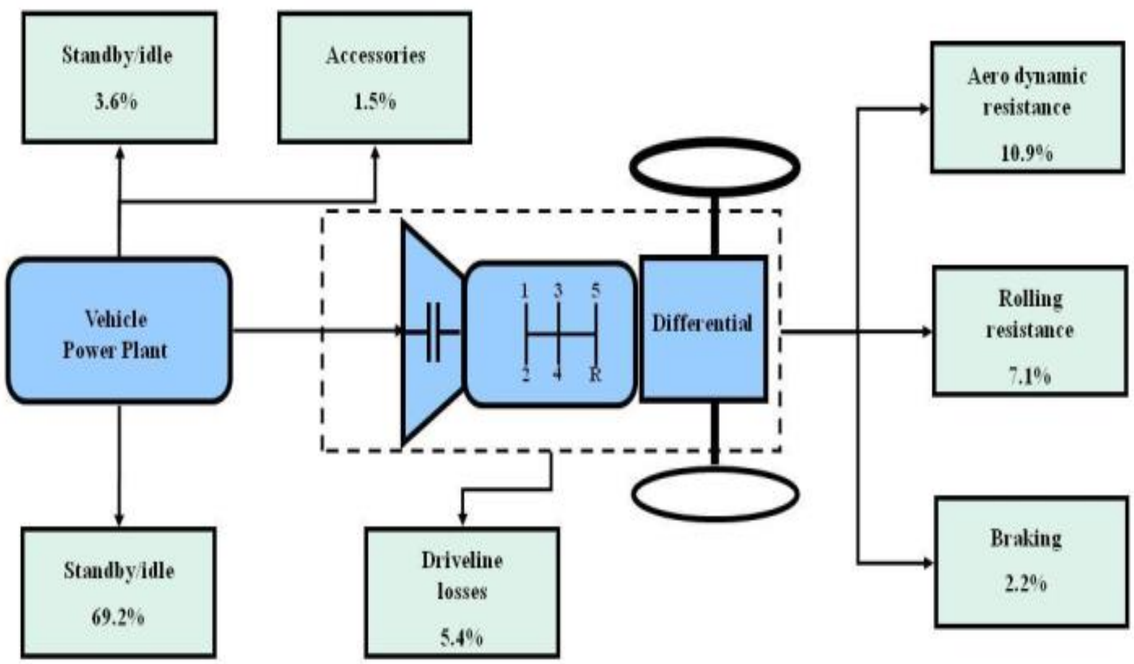

Figure 1 Translation of fuel energy in to work in a conventional vehicle M.Ehsani (2005)

Hybrid Electric Vehicle

The advantages of hybrid vehicles over the conventional vehicles are;

- **More efficient operation of the ICE, including reduction of idle: -** the energy loss associated with engine operation at speed and load combination where the engine is in efficient can be avoided by hybrid vehicles. This allows internal combustion engine (ICE) to operate at speed and loads where it is most efficient. When an HEV is stopped, rather than running the engine at idle, where it is extremely inefficient, the control system may either shut off the engine, with the storage device providing auxiliary power (for heating or cooling the vehicle interior, powering headlights, etc.), or run the engine at a higher-than-idle (more efficient) power setting and use the excess power (over auxiliary loads) to recharge the storage device. When the vehicle control system can shut the engine off at idle, the drivetrain can be designed so that the drive motor also serves as the starter motor, allowing extremely rapid restart due to the motor's high starting torque M. Ehsani (2005).

- **Regenerative braking: -** Is a mechanism by which the energy lost as heat to the mechanical brake is captured by using its electric drive motor in generator mode to brake the vehicle.
- **Smaller ICE: -** ICE can be down sized since the storage device can take up a part of the load. It can be sized for the continuous load and not for the very high short-term acceleration load. This enables ICE to operate at higher traction of its rated power, generally at higher fuel efficiency, during most of driving.
- **Electric launch: -** In some configurations, the motor alone can be used to accelerate from a stop, avoiding a driving mode where the engine in a conventional drivetrain would be

  particularly inefficient.

Types of Hybrid Electric Vehicle (HEV)

Hybrid Electric Vehicle is a type of technology which indulges both mechanical drive train and electrical drive train. Mechanical drive train includes fuel tank, combustion engine, gearbox and transmission to the wheels while an electrical drive train consists of battery, electric motor and power electronics for control as shown in Figure 2 and Figure 3. So, the mechanical and electrical drive train concept can be implemented in to hybrid drive train concept by different configuration as follow.

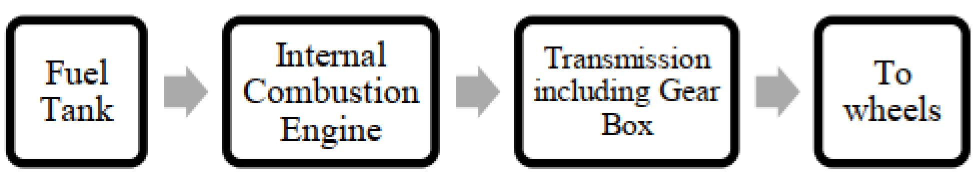

Figure 2 Flow of energy within a mechanical drive train C.Prajapati et al., (2014)

The configuration in Figure2 shows that mechanical drive train in which the fuel tank provides fuel for internal combustion engine, and through the crank shaft power will be delivered to the transmission gear box and then to the wheels.

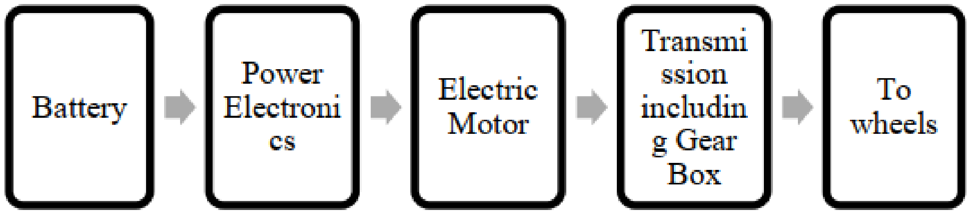

Figure 3 Flow of energy within an electric drive train C. Prajapati et al., (2014)

The configuration in Figure 3 shows power flow in the electric vehicle. Power from the battery is provided to the motor via power electronics then to the transmission gear box which is then lead to the wheels.

1. Series hybrid configuration
2. Parallel hybrid configuration
3. Series parallel hybrid configuration
4. Complex hybrid configuration

Series hybrid configuration

The series structure is similar to an electric vehicle with the addition of an engine to power a generator that provides electrical power to the battery and/or to the electric motor to extend the range of the vehicle.

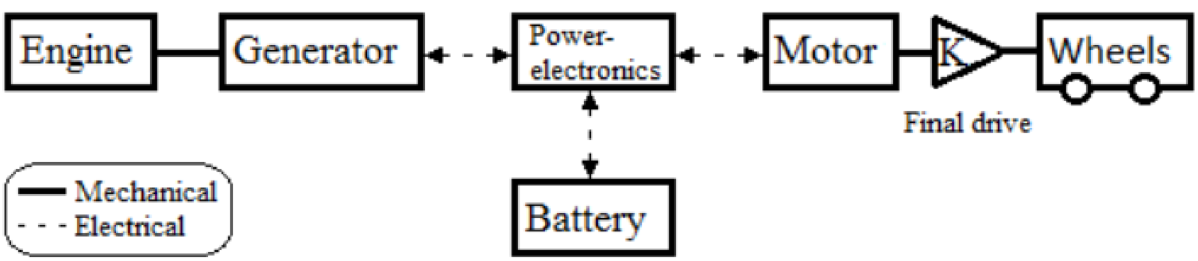

Figure 4 Schematic of a series hybrid structure C. Prajapati et al., (2014)

Power flow in series hybrid electric vehicle as shown in Figure4 is almost similar to the electric vehicle except electric vehicles don’t use engine. power from the engine is used to drive generator and supply power to the motor which delivers power to the wheels.

Parallel hybrid configuration

The parallel HEV allows both ICE and electric motor (EM) to deliver power to drive the wheels. Since both the ICE and EM are coupled to the drive shaft of the wheels via two clutches, the propulsion power may be supplied by ICE alone, by EM only or by both ICE and EM.

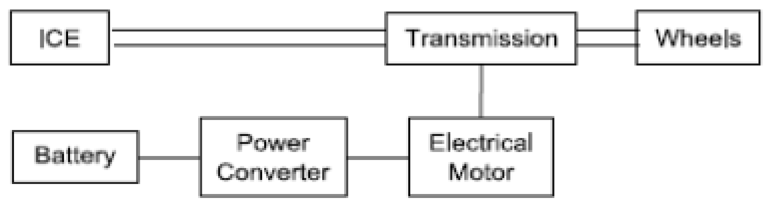

Figure 5 Parallel Hybrid Structure C. Prajapati et al., (2014)

In parallel hybrid electric vehicle configuration, we can see that internal combustion engine and electric motor provides power to the wheels at the same time. As it is shown in the Figure5 power from battery is provided to electric motor via power convertor which is then provided to the transmission which finally delivers it to the wheels.

Series-Parallel configuration

In the series-parallel hybrid the configuration incorporates the features of both the series and parallel HEVs. However, this configuration needs an additional electric machine and a planetary gear unit making the control complex.

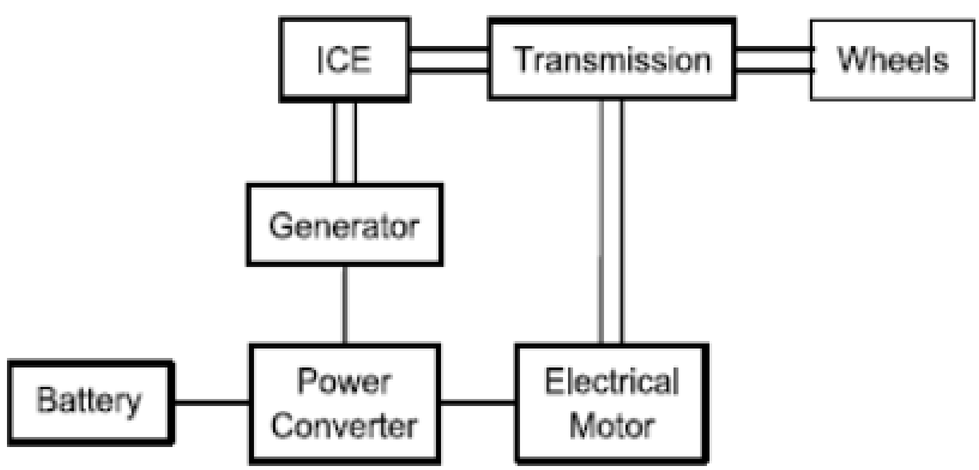

Figure 6 Series-Parallel Hybrid Structure C. Prajapati et al., (2014)

Complex configuration

There are two separate mechanical links obtaining a light transmission system and a flexible mounting. As an example, the front wheels are powered by hybrid propulsion, while the rear wheels have a pure electric system. There is a wi-deflexibility on the power flux managing C. Prajapati et al (2014).

1.3. Statement of the Problem

As we can see in the world the main source of energy for vehicles and other transportation system are fossil fuels. These fuels will result in a harmful emission of gases which contribute negative impact to the environment. This is one of the biggest problems that the world is facing this day. The other problem is too much consumption of fuel by different vehicles since all of our vehicles in Ethiopia are dependent on fossil fuel the money wasted for fuel is too much.

So, as an automotive Engineer this thesis focuses on technology that will reduce the pollutant emission that is produced due to vehicle working on fossil fuels and reduce fuel consumption. Among this technology changing conventional Bajaj Quet to hybrid Bajaj Quet is one of them which reduce the emission of harmful gaseous substance. The hybrid Bajaj Quet causes less damage to the environment than the conventional Baja Quet so this project is really helpful to reduce environmental pollution caused by conventional ICE Bajaj Quet.

1.5. Objectives

1.5.1. General Objective

The main objective of this thesis work is to design and simulate transmission system for four-wheeler hybrid electric Bajaj Quet using MATLAB Simulink.

1.5.2. Specific Objectives

The specific objectives of thesis work are: -

1. To collect the necessary data for the system design.
2. To model and simulate power train.
3. To model appropriate motor which provide the required energy/power for HEV Bajaj Quet.
4. To model appropriate battery which provide the required energy/power for HEV Bajaj Quet.
5. To model and analyze the regenerative braking system.

1.6. Scope of the study

The scope of this work includes design and simulation of transmission system for four-wheeler hybrid electric Bajaj using MATLAB Simulink, design and analysis of motor and battery. Modeling and analysis of the regenerative braking system is also included in this work. Experimentation and preparation of prototype is not included in this work.

1.7. Significance

Providing a good and green transport is very necessary in urban areas. In this recent decade we are seeing technology that promote green vehicles (i.e. hybrid or full electric). So, designing transport vehicles that fully utilize electricity or both electric and fuel are very important. Especially in developing countries like Ethiopia it is vital to introduce to the market. Generally, hybrid electric Bajaj will have the following advantages, lack of fuel will be reduced, reduce money expenditure on fuel due to more consumption of fuel and government will not expend more foreign currency on fuel.

1.8 Limitation of the work

The challenges which are faced on this thesis are.

- Lack of manufacturing facilities
- Budget scarcity
- Difficulty of determining road driving cycle in our country.

1.9 Thesis organization

This thesis consist of five chapters and essence of each chapter is detailed below.

The first chapter is about giving introduction, background of study, problem statement, objective, research scope, limitation of the work, and organization of thesis. In the second chapter literature review of some other researches about level of hybridization and detail component studies are discussed.

In chapter three the methodology of the thesis was discussed. Detail discussion and modeling of the Bajaj Quet using MATLAB/Simulink have been done. The result from the modeling in chapter three was discussed in chapter four. Finally, in chapter five conclusion and recommendation was done.

CHAPTER TWO
LITERATURE REVIEW

The development of this project is started from thorough investigation/or review of existing literature on the topic. There have been many researches about hybrid technology in the past, experimentally, theoretically and by using different software. A rigorous search was done to find any journals articles written on the subject and some of the studies/researches are reviewed as follows.

Karen.L Butler et al (1999) discussed the methodology for designing vehicle drive train by using v-Elph package which is written in the MATLAB/SIMULINK graphical simulation language and is portable to most computer platforms. An electric vehicle (EV), series and parallel hybrid electric vehicles, and a conventional internal combustion engine (ICE) drive train have been designed by using the simulation package. Simulation result such as fuel consumption, vehicle emission and complexity are compared and discussed for each vehicle

Dragan simic et al (2018) worked on different mechanical and electrical modeling of different configuration of hybrid electric vehicles. The implemented simulation models and calculated results were performed with modelica using Dymola.

Herald Givliani et al (2006) deals with a comparison a conventional vehicle with manual transmission and parallel hybrid electric vehicle with a starter/generator for investigation of the fuel consumption. The whole vehicle simulation is developed with a Smart Power Train Library and Smart Electric Drives Library. The computer simulation result shows the improved fuel consumption of the hybrid electric vehicle.

2.1 Levels of hybridization

When designing hybrid electric vehicles there are a number of important factors that needs to be considered, like, sizing internal combustion engine and electrical machines. Based on the size of internal combustion engine or electric machines HEV's are categorized in to different levels of hybridization, like micro, mailed, full and plug in Ivar Roskifte Leikarnes (2017).

Micro hybrids only support a start stop function where the engine shut down when the vehicle stops and restarts when the brake pedal is released. Mild, full and plug-in hybrids have the function of regenerative braking in addition to assist in vehicle propulsion, whereas the micro hybrids do not support these features.

2.2 Main components of HEV

2.2.1 Internal combustion engine (ICE)

The majority of HEV's use internal combustion engine in their design. Compared to the other fossil-fueled engine the diesel and gasoline engine has higher power to weight ratio and a wide range of operation interns of rotational speed. The selection ICE in a HEV's power train depends on the drivability requirements and level of hybridization. Since micro and mild hybrids offer no or little assistance from the electrical machine to the propulsion of the vehicle the engine must have similar specification to that of an equivalent conventional vehicle in order to meet the same performance in terms of drivability. Full hybrids have greater involvement of electric power so the engine can be smaller Ivar Roskifte Leikarnes (2017).

2.2.2 Batteries

A battery is an energy storage device that converts chemical energy in to electrical energy. The accumulator is built of one or more voltaic cell and each cell consist of two half cells, connected in series by a conductive electrolyte, half-cell acts as positive electrode/or anode and the other half is negative electrode/or cathode Gustaf lagunoff (2008).

Batteries are very essential for hybrid electric vehicles (HEVs), plugin hybrid electric vehicles (PHEVs), and electric vehicles (EV). Batteries must be rechargeable and capable of storing sufficient energy for starting the engine or long-range driving and capable of delivering sufficient power to the motor according to the type of vehicle. A common nominal voltage of battery module is 12v, 24v, 36v, 48v, 60v, 72v, and 96v B. Freyr (2011).

Types of Batteries

There are different types of electrical energy storage devices like lithium based, nickel based, Lead acid batteries and ultracapacitors are some of them.

Lithium ion batteries

Lithium ion batteries are currently used in most portable consumer electronics such as cell phones, laptops and electric vehicles, because of their high energy per unit mass relative to other electrical energy storage systems. They also have high power to weight ratio high energy efficiency, good high temperature performance and low self-discharge.

Lithium ion battery electrodes need to comply with two important features an open crystal structure which allows insertion or extraction of lithium ions and in the same time the ability to accept compensating electrons because lithium itself reacts strongly with water, the electrolyte of lithium ion battery is a non-aqueous organic salt and functions only as conductor and doesn't take part in the chemical reaction at all I. Reskifte (2017).

In this design lithium batteries are used since lithium is the lightest of all metals and presently very interesting characteristics from an electromechanical point of view. It allows a very high thermodynamic voltage which results in a very high specific energy and specific power, it can undergo multiple reduction/redox cycles, the user shall be able to recharge the battery, by using the battery charger.

Nickel based batteries

Nickel is lighter metal than lead and has very good electrochemical properties desirable for battery applications. There are four different nickel-based battery technologies. Nickel iron, Nickel Zink, Nickel Cadmium and Nickel MH M. Ehsani (2005).

Lead acid batteries

Lead acid batteries are known as a part of a conventional vehicle where they function as starter batteries. These batteries are designed to deliver pulsed power, that is large amount of energy during a short period of time.

Lead acid batteries are very old design to the date but, still remain a popular choice when it comes to automotive energy storage. The main reason is its comparatively low cost and an existing infrastructure for charging, servicing and recyclable disposal. The drawback of lead acid batteries is high mass due to very high density of lead, low energy density, lead is environmentally unfriendly.

Different lead acid batteries with improved performance are being developed for EVs and HEVs. Improvement of sealed lead acid batteries in specific energy over 40kw/kg with the possibility or rapid charge have been attained

The number of times the battery can be discharged is known as batteries life cycle. The cycle life determines its suitability in different conditions. Car batteries are most common types of lead acid batteries but they will survive only five or ten cycles. For hybrid or electric vehicle application the battery needs to be capable of being discharged hundreds or even thousands of times. These types of battery are known as a deep-cycle battery and some of the many different types based on number of discharges are listed below Mesfine mitiku (2012).

1. Leisure batteries

Leisure batteries or caravan batteries are usually the cheapest types of deep cycle battery. They look similar to a car battery but have different plate construction their capacity is normally in the range of 60 to 120Ah at 12volt, making them most suitable for smaller systems. The cycle life of leisure batteries is limited to a few hundred cycles. Meaning that they are most suitable for systems which will not be used every day such as those in caravans or holiday Mesfine Mitiku (2012)

Figure 7 Leisure batteries

2. Traction Batteries

The term traction battery relates to all batteries used to power electric vehicles. This can mean anything from a mobility scooter to a fork lift truck, so encompasses capacities from 30 to 40 Ah to many hundreds. The smaller traction batteries are usually 6 or 12volt units, where the largest are single 2-volt cells. Traction batteries are ideal for solar power application as they are intended to be fully discharged and recharged daily. The larger traction batteries can with stand thousands of discharge cycles. There are also batteries known as semi-traction batteries which can be thought of as higher quality leisure batteries exhibiting a greater cycle life. Marine batteries also fall in to this category.

Figure 8 Traction batteries

3. Sealed batteries

There are many sealed lead-acid batteries ranging from those of 1 or 2 Ah to single cell traction batteries of hundreds of Amp-hours. The advantages of sealed batteries are they do not need maintenance and are spill-proof. The disadvantage of sealed batteries are they are expensive than other batteries, they require more accurate charging control and can have a shorter life, especially at high temperature.

Figure 9 Sealed batteries

2.2.3 Electric machine

As there are different degree of hybridization of hybrid electric vehicles there will be different demand for electric machines. In the case of mild hybrid system electric motor should exhibit, start/stop alternator and regenerative breaking. There are different motor technologies used in hybrid or electric vehicles.

- Brushed DC motor: - This type of motor consists of a stationary field system and rotating armature/brush gear commutation system. The field can be series or shunt wound depending on the required characteristics. The main drawback of this type is weight compared with alternative technologies consequently polaron believes DC is best at lower powers overall, due to the built-in commutation scheme.
- Brushless DC motor: - Brushless DC motor is mechanically different from the brushed DC motor in that there is no commutator and the rotor made up of lamination with a series of discrete permanent magnets inserted into the periphery. In this type of machine, the field system is provided by the combined effect of the permanent manet and armature reaction from vector control. Similar in principle to the synchronous motor, the rotor of this machine is fitted with permanent magnets with lock on to a rotating magnetic field produced by the stator.
- Switched Reluctance motor (SRMS): - Switched reluctance motor use controlled magnetic attractor in the 6/4 arrangement to produce torque. Existing SR drives are Unipolar, in that the voltages applied to windings are only one polarity. This was done to avoid shoot through problem in the power devices of the inverter. SRMs are both heavier and less efficient than PMBDC machines.
- Induction motor (IM): - Induction motor is used in a very wide range of applications, from cassette player to large trains. The main reason why the induction machine is so popular is the simple design, as it is not equipped with any brushes or permanent magnets the cost is relatively low. Compared to others the main drawback of the IM is that somewhat difficult torque control. The difficult task is to estimate the flux wave position. For a SM/synchronous machine the flux wave can easily be determined by the help of the rotor position and the current but for the IM, the position does not provide only information since the flux rotates relative to the rotor as well.

2.2.4 Motor controller

Motor Controller is a device operating between the battery and the motor. Batteries store electrical energy with DC power and that is also what can be extracted from it. Motors on the other hand use AC current or multiphase DC current. So, motor controllers are needed to convert the DC power from the batteries to AC power for the motor. The motor controller circuit delivers the voltage to DC motor with pulses and the speed is controlled via PWM/pules width modulation. Generally, the controller supervises the entire system to enhance overall system performance and stability Mohamed.a El. Sharkawi (2000).

2.2.5 DC/DC converter

The DC/DC converter is designed for a wide range of input voltage. As it is likely for multiple voltages to exist in HEV's DC/DC electrical energy conversion alters the voltage of a DC power source from one level to another Gustaf Lagunoff (2008).

If the storage device would have been connected directly to the DC-motor the current would be extremely high until the DC motor would be up to speed corresponding to the voltage in the storage device. If this was done in the car this time would be very long and the motor would be thermally damaged. The rest of the power train would break as well because of this high torque. To achieve a smooth acceleration the voltage applied to the motor needs to slowly increase, this is handled by the converter. The voltage can be set to any level needed, giving any speed needed, and also apply voltage in the opposite polarity making the motor spin backwards J.Karlsson. et al (2009).

2.2.6 Planetary gear train

Planetary gear system is a center of the hybrid power train which combines power from the engine and motor to produce the desired output speed at the wheels. The system normally consists of a centrally pivoted sun gear, a ring gear, and several planet gears found between the sun gear and ring gear. Planetary gears have some advantages over the conventional or normal gear box. The advantages are compactness high torque to weight ratio, reduced radial bending loads, more accurate, high precision high efficiency and less power loss S.N. Shaikh et al (2017). Now, industrial applications demand high torque in compact (a high torque/volume) and light (a high torque/weight ratio) package. In planetary gears, torque density can be increased by adding more planets through multiple gear mesh points. This means a planetary gear with say three planets can transfer three times the torque of a similar sized fixed axis standard spur gear system P. Vitthal Pawar et al., 2015.

Working principle of planetary gear box

The hybrid drive train consist of two motors (i.e motor generator one (MG1) and motor generator two (MG2)) and one internal combustion engine (ICE) each of this component are connected to different planetary gear parts. Motor generator one MG1 is connected to sun gear, Motor generator two MG2 is connected to ring gear, internal combustion engine ICE is connected to planet carrier.

MG1 is a starter motor for both internal combustion engine and MG2, as MG1 turns it turns the engine or start ICE, as the engine turns and continues to turn it will turn MG1 and makes it an alternator that will charge the battery. The engine can start and stop as it is necessary to charge the battery.

As motor generator two starts to turn the vehicle will move and if it is stopped it will stop. When MG2 tuns it will turn MG1 in the opposite direction and this stage only electric motor power is being used (i.e. DC voltage from battery is converted to AC and turning MG2)

Chiao-Ting et al (2012) designed a systematic design methodology for split hybrid vehicles using a single planetary gear set as a transmission. The design methodology consists of four steps

I. Analyze clutch location on the planetary gear and operation mode
II. Generate dynamic models
III. Evaluate drivability (acceleration performance) via forward simulation
IV. Optimize fuel economy using dynamic programing technique

This methodology systematically evaluates 12 configuration candidates and identify the optimal design.

Antoni Szumanowski et al (2010) presented a new compact hybrid planetary transmission drive (CHPTD) as a solution of plug in hybrid electric vehicle (PHEV). The presented CHPTD is more compact and lower cost than the other series parallel hybrid drives equipped with planetary transmission and two motors. The advantages of planetary transmission which is s power summing mechanical unit, was obtained by proper design and control of innovative high energy saving electromagnetic clutch/ brake device based on classic dual diaphragm spring system.

S.B.Nandeppagoudar et al (2017) redesigned 3 stage planetary gear box by reducing on stage which will be suitable for machine tool application where the space and load constraints is the primary objective. Analytical and effective ness of modified planetary gear box. It is observed that the analytical and numerical methods are one and the same therefore the new designed gear box for high reduction ratio and space reduction is satisfied.

Many researchers have studied the fuel consumption and emission reduction of hybrid electric vehicles experimentally, theoretically and by using different soft wares. Some of the studies /researches are reviewed here as follows:

R. Capata et al., (2010) the interest of the UDR1 research group has focused on the development of a Hybrid Series (HS) vehicle, different from the standard one thanks to the use of a Gas Turbine set (GT) as a thermal engine. The reason for this choice resides in the opportunity to reduce weight and dimensions, in comparison to a traditional Internal Combustion Engine (ICE). It is not possible to use the GT engine set directly for the vehicle traction, therefore the UDR1 HS configuration shows the GT set connected with the electric generator only. The result is that the traction is purely electric. The resulting engine configuration is a commonly defined Hybrid Series. Many efforts are spent in the definition of a generic scientific method to define the correct ratio (Degree of Hybridization) between the installed power of the battery pack and that of the GT electric generator, which simultaneously guarantees the life of the battery pack and the capacity of the vehicle to complete a common mission without lack of energy or stopping. This article reports a method to define the power ratio between battery pack and GT generator, applied to a recent commission for the development of a mini city

Karen et al., (1999) Presented and modeling package developed at Texas A&M University, V-Elph 2.01. VElph facilitates in-depth studies of electric vehicle (EV) and hybrid EV (HEV) configurations or energy management strategies through visual programming by creating components as hierarchical subsystems that can be used interchangeably as embedded systems. V-Elph was written in the Matlab/Simulink graphical simulation language and is portable to most computer platforms. This paper also discusses the methodology for designing vehicle drive trains using the V-Elph package. An EV, a series HEV, a parallel HEV, and a conventional internal combustion engine (ICE) driven drive train have been designed using the simulation package. Simulation results such as fuel consumption, vehicle emissions, and complexity are compared and discussed for each vehicle.

D. Simic et al., (2006) In this paper fuel consumption of two vehicles were compared. For investigating the fuel consumption, a whole vehicle simulation is developed with a Smart Power train library and the Smart Electric Drives library, both libraries are written in Modelica language. As a reference vehicle a conventional vehicle with manual transmission is modeled. A parallel hybrid electric vehicle with a starter/ generator and two transition. machines at the front and rear drive train wheels is compared with this reference vehicle. The computer simulation result shows the improved fuel consumption of the hybrid electric vehicle.

T. Bauml et al., (2008) This work dealt with mechanical and electrical modeling of different configurations of hybrid electric vehicle. The implemented simulation models and calculated results were performed with Modelica using Dymola. Three Modelica library packages specifically developed for modeling and simulation of the mechanical, electrical and control components of automotive components have been used. Smart electric drives vehicle interface and power train library.

C. Prajapati et al (2014) discussed the technologies used in the making of Hybrid Cars such as "Hybrid Solar Vehicle", "Hybrid Electric Vehicle" and "Plug In hybrid electric vehicles". This work is based on the explanation of such technologies, their function, drawback of this technology, efficiency of Hybrid Cars, Case studies on the present commercial hybrid cars such as Toyota Prius series, Astrolab etc and the fuels and raw materials used in the Hybrid Cars. Paper concludes on the advantages and dis-advantages of Hybrid Cars and how this technology will take over the world in future and would become the alternative for Petrol and Diesel Cars.

T. Keulen et al (2010) dealt with two difficulties in the design of an energy management strategy. Firstly, the nonlinear behavior of the components results in a nonconvex cost function, complicating the use of optimization methods. Different approaches to deal with the nonconvexity are discussed. Secondly, the future power and velocity trajectories are unknown. Prediction of the future trajectories, based upon either past or predicted vehicle velocity and road grade trajectories, could help in obtaining a solution close to optimal. The benefit of prediction, compared to a heuristic and an optimal control strategy that uses only actual vehicle data, is shown with an example of a hybrid truck at a highway trajectory in a hilly environment. Results indicate that prediction has benefits only when the slopes have sufficient grade and length, such that the battery state-of-charge boundaries are reached. The simulation example in this paper shows that one can find examples where the benefit of prediction ranges from marginal to substantial, depending upon the route and vehicle characteristics.

Ivar Roskifte Leikarnes (2017) presented an overview of the different types of hybrid electric vehicle structures and basic guidelines regarding choice of components. The simulation model of a hybrid electric vehicle was created for this thesis to investigate the impact on fuel efficiency in relation to rolling resistance coefficient and vehicle weight. Although the model is not designed for optimal engine operation, the results indicate that lower rolling resistance coefficient and lower vehicle weight leads to reduced fuel consumption. Proposed improvements to the simulation design are presented in the report.

H. Zhao et al (2015) studied a series-parallel hybrid powertrain configuration for the medium-duty plug-in hybrid trucks and Volt-like passenger cars. The series-parallel hybrid combines the features of the parallel hybrid and the series hybrid. Series-parallel hybrid powertrains with pre- and post-transmission configuration for the plug-in hybrid medium-duty trucks were modelled and compared with a conventional diesel and a mild/full parallel hybrid with pre-transmission configuration to explore the greatest possible benefit of fuel economy by powertrain hybridization. A control strategy for the series-parallel hybrid vehicle was developed, where the electric motor and the engine can work individually or together, depending on the speed and the power required for driving the vehicle and the state-of-charge (SOC) of the battery. The simulations were performed over the urban drive, highway drive, urban heavy-duty drive, and the local parcel delivery drive cycles. The simulation results show that series-parallel are well suited to medium duty parcel delivery vehicle applications within the range of 50-100 miles. The Volt-like PHEV utilized a gasoline engine and the vehicle fuel economies were compared for the series-parallel and single-shaft approaches for various city and highway driving cycles.

B. STUMBERGER et al (2011) presented characteristics of a permanent magnet synchronous machine designed for micro-hybrid electric vehicle operation. Appropriate design of interior permanent magnet machine with 36 stator slots and 8 stator poles for operation in motor and generator operation mode was investigated. Finite element analysis is employed in order to determine the machine performance. The results presented in the paper clearly show potential of the presented PM machine for belt-driven starter-generator applications.

J. KARLSSON et al (2009) designed and build a test bench for a small hybrid electrical vehicle was designed and built. In particular it was designed since Chalmers is building a car to be able to compete in Shell ECO-marathon. This car is going to be a hybrid car using petrol as primary energy and electricity as secondary source. The resulting drive train system which was first tested in the rig was a series hybrid using a 35 cc 4-stroke engine with two brushed DC-motors attached to it via a chain. These are directly connected to a super capacitor with a soft start in between to be able to connect them in a smooth way. By doing this, the generators are also used as a start engine. The drive motor is also a brushed DC-motor connected to the super capacitor via a converter. All parts of the test bench are controlled by a PLC system. Interesting quantities are measured and logged to be able to analyze the data to calculate efficiency etc. The test bench is complete and working for a series hybrid with an ICE of about 1 kW. The test bench can be modified to a parallel electrical hybrid set-up with reasonable efforts and be used to optimize Smarter for future years.

T. MOHANTY (2013) designed and fabricated a two-wheeler hybrid electric vehicle powered by both battery and gasoline. The combination of both the power makes the vehicle dynamic in nature. It provides its owner with advantages in fuel economy and environmental impact over conventional automobiles. Hybrid electric vehicles combine an electric motor, battery and power system with an internal combustion engine to achieve better fuel economy and reduce toxic emissions. In HEV, the battery alone provides power for low-speed driving conditions where internal combustion engines are least efficient. In accelerating, long highways, or hill climbing the electric motor provides additional power to assist the engine. This allows a smaller, more efficient engine to be used. Besides it also utilizes the concept of regenerative braking for optimized utilization of energy. Energy dissipated during braking in HEV is used in charging battery. Thus, the vehicle is best suited for the growing urban areas with high traffic. Initially the designing of the vehicle in CAD, simulations of inverter and other models are done. Equipment and their cost analysis are done. It deals with the fabrication of the vehicle. This includes assembly of IC Engine and its components. The next phase consists of implementing the electric power drive and designing the controllers. The final stage would consist of increasing the efficiency of the vehicle in economic ways.

L. Tribiol et al (2011) with the present paper the Authors intend to lay the basis of a comprehensive methodology, which can allow to simply define an optimized powertrain layout, i.e. architecture and devices size, and an efficient control strategy. To this aim, research group has developed an analytical code that simulates the power flows in HEV powertrain and allows to calculate the performances of a specific vehicle upon various and different missions. By knowing the energy required, the model allows to define a range of admissible states for each time step, resulting of the combination of the engine power and the corresponding motor power, considering regenerative braking and constraints imposed by the engine, the motors and the storage system. The best solution between all possible layouts is found with Dijkstra shortest path optimization algorithm electing the configuration allowing the minimum fuel consumption.

Oguz H. Dagci (2018) introduced an automated design process for PG based HEV systems focusing on both fuel economy and performance, while also deriving the necessary analysis and synthesis tools. First, the design process generates all possible modes in an HEV design with a given set of powertrain components. Second, all powertrain types to be realized with a given set of components are mathematically shown, and each feasible mode is classified under one of these powertrain types. Third, computationally efficient linear programming solvers suitable for vector operations are developed for each powertrain type. Fourth, the combination of modes that meets the performance requirements, along with the number and location of clutches that make these mode transitions possible, are identified. As a result, each potent mode combination, the clutches necessary for the mode transition, and the auxiliary modes established through all clutch state combinations constitute a design that meets the performance criteria. Last, the fuel economy improvement potential of each design is evaluated using an algorithm that approximates dynamic programming optimization. The results show that light-duty truck performance requirements can be met by many two-PG HEV designs without sacrificing fuel economy if the right analysis and synthesis techniques for exploring the entire design space are developed. In addition to the design process, the feasibility of mode transitions and the effect of mode transitions on the fuel economy simulation results are investigated. For this purpose, the dynamics of mode transition is analyzed, and control algorithms achieving the transitions without interrupting the desired vehicle torque are developed. Then, these analysis and synthesis techniques are automated so that they can be integrated into the fuel economy simulation algorithm. The simulation results reveal that some mode transitions have a negative effect on fuel economy and the assumption of mode transition feasibility at any operating point is not valid.

Boukehili Adel et al (2010) focused on developing, a parallel HEV hybrid controller is developed in the MATLAB/Simulink environment. Using the driver commands, the battery state of charge and the engine map, a set of efficient rules has been developed to efficiently split the power between the engine and the motor. The steps are: 1) Estimate the instantaneous torque demand. 2) Using the estimated torque, the feedback signals and the engine map, find the best operating point and then split the power and let the engine work as near as possible to this efficient point, that can be done by controlling the motor (or generator). In the case of motor, let its torque supply the rest of the torque needed, while the engine works near its efficient point, or in the case of generator, let its torque supply an additional load to put the engine in an efficient point. 3) Control the motor to supply the transient torque demand, and keep the engine torque constant as long time as possible, this help to reduce fuel consumption. Finally, simulations of a conventional and hybrid vehicle are performed using Simulink environment to check the controller and series of results will prove the effectiveness of the proposed controller and will show the advantage of hybrid powertrain over conventional one in term of fuel economy**.**

M. Beliveau et al., (2010) focused on hybrid vehicle technology and its integration into society. The encompassing issue answered in this project was whether hybrids meet the expectations for environmental benefits suggested by many people. Research was done is the areas of types of hybrids, consumer trends, and the future of hybrid technology. Hybrid production and efficiency data were analyzed to examine the technical aspects of the technology. A focus group of people who recently bought cars, both hybrids and non-hybrids, revealed what consumers look for in their cars. Analysis of the needs of hybrid technology helped determine how feasible widespread change to hybrids would be in future. With all information taken into account, we concluded that hybrids have several drawbacks that offset their fuel efficiency. Their higher price both turns consumers away and makes the vehicles a less attractive economic investment. Energy efficient processing techniques need to be developed before the advanced materials in hybrids can help add to their clean image. Widespread change to advanced hybrid technologies is not a feasible option in the near future because of both cost and the limited number of hybrids on the road today. Overall, hybrid technology has a lot of potential in the distant future, but as for right now they are not a significant improvement over today's internal combustion engine.

CHAPTER 3
RESEARCH METHODOLOGY

3.1. Data collection

In this research both primary and secondary data collection methods have been utilized. **Primary Data Sources***:* Direct observation and by interviewing the concerned bodies. Dimensions of the vehicle are obtained by direct measurement using different measuring devices.

Secondary Data Sources: The secondary data required for completing this task was gathered by reviewing of books, journals, magazines etc… and by browsing related websites.

The various stages of the project are.

I. Literature review

II. Required component specification
   - Determination of the size of each part.
   - Modeling of parts using Solid work.
   - Calculation of the power, torque and speed of the motor required for Bajaj Quet.
   - Calculation of the controller for the battery and motor.
   - Determination of the planetary gear ratio, torque and speed.

III. Modeling and Simulation

The power train components i.e. motor, battery, DC/DC converter and regenerative braking systems were modeled and simulated by using MATLAB Simulink.

3.2 Design Analysis

Conceptual design was developed which includes power train, battery, electric motor, regenerative braking, and the transmission system.

3.3 Expected out puts

After completion of the study the expected results are.

- Design of new transmission which include battery and motor system for Bajaj Quet.
- Design of suitable power train for Bajaj Quet.
- Better overall performance.

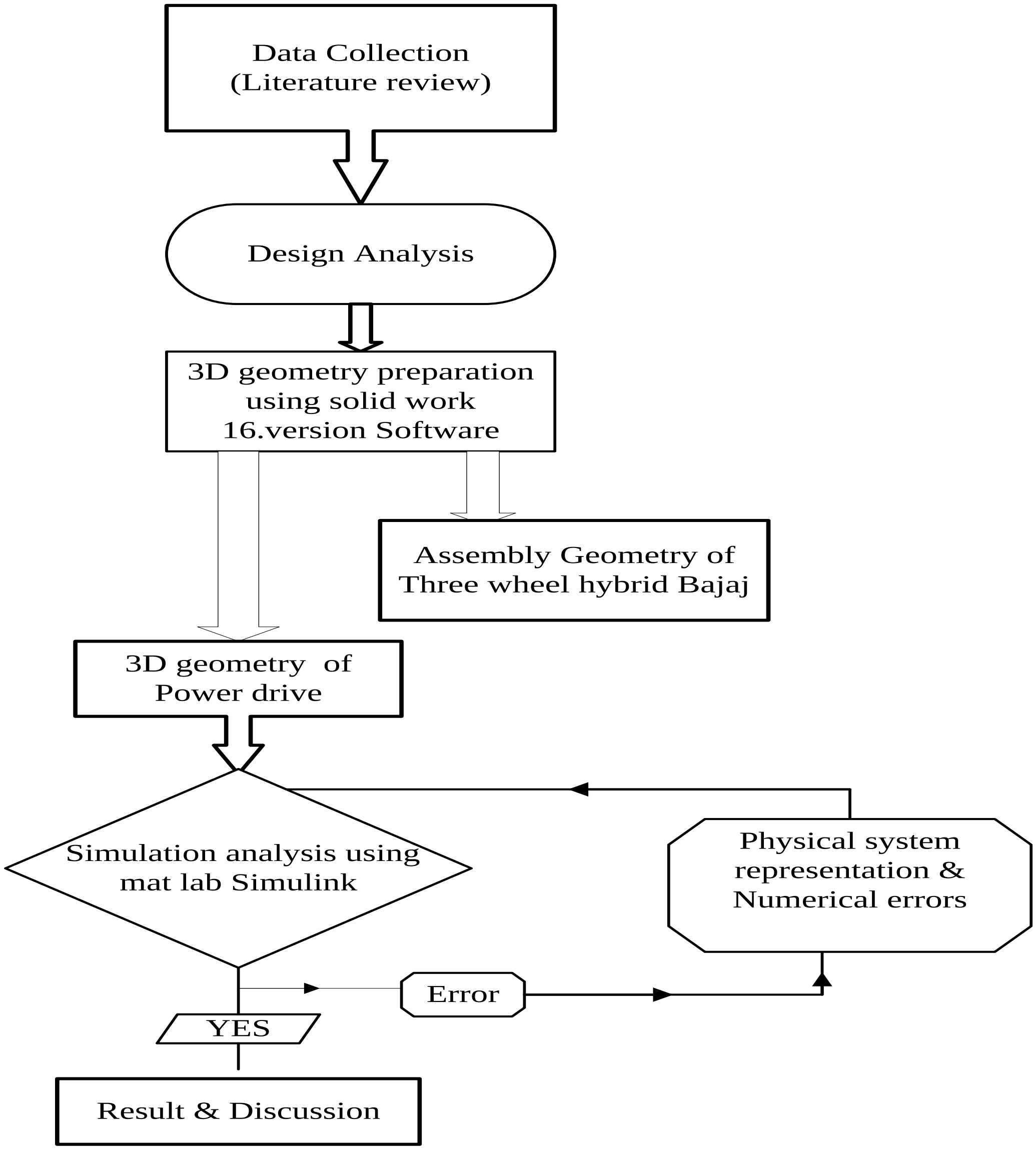

Figure 10 Flow chart of the study design

As it is shown in Figure10 this thesis is started by collection of data(reviewing literatures) analyzing the design and 3D geometry preparation by using solid work soft ware and modeling of components by using MATLAB Simulin then simulation analysis was conducted wich finaly leads to result and discussion.

3.4 System Design

3.4.1 Specification of existing bajaj Qute

The technical specification of the existing Bajaj Quet was obtained from the taining manual of Bajaj Quet and from field measurement. The training manual was provided by Horra Trading PLC. Horra Trading PLC is the only importer of Bajaj Quet to Ethiopia.

Table 3.1 Vehicle Specification of the existing Bajaaj Quet

ENGINE AND TRANSMISSION	
Engine type	Four stroke, spark ignition single cylinder oil cooled
Bore * Stroke (mm)	63.5 * 68.4
Engine Displacement (cc)	216.6
Compression ratio	11:1
Power	9.9 KW @ 5500+250rpm as per IS; 14599;1999
Torque	19.6 Nm @ 4000+ 150rpm as per IS; 14599;1999
Starting	Electric start
Spark plug	3 spark plug
Spark plug gap (mm)	Central (0.8-0.9), side left hand and right hand (0.6-0.7)
Idling speed	1250 +/- 150 rpm as per IS; 14599;1999
Clutch	Wet multi disc clutch
Transmission	Constant mesh manual 5 forward and 1 revers speed
CHASIS AND BODY	
Chasis type	Monocoque chasiss
SUSPENSION	
Front independent	Independent suspention, twin leading arm
Rear	Independent suspention, coil spring semi trailling arm
Brakes	Hydraulic with H-split. All drum with diameter 180
Parking	Mechanical (cable operated) hand operated rear wheel braking
WHEEL RIM	
Front	135/70R12 (Radial tubeless)
Rear	135/70R12 (Radial tubeless)
Spare	135/70R12 (Radial tubeless)
TYRE PRESSURE	
Front and spare	2.1Kg/cm^2 (30PSI)
Rear	2.4 kg/cm^2 (30PSI)
Fuel Tank capacity	8 liters (nominal petrol)

ELECTRICAL SYSTEM	
Battery	12v,26AH
Head lamp	35 * 35W HS1
Tail stop lamp	5 * 21 W
Side indicator lamp	5W
Horn	12V DC-DIA 82
Reverse Lamp	10W
Wiper Motor	10volts single speed
Engine Management	ECU, fuel injected
F/R Indicator Lamp	10W
Front position Lamp	3W
Cabin light	10W
DIMENSION	
Length	2752mm
Width	1312mm
Height	1652mm
Wheel Base	1925mm
Ground Clearance	180mm, Unladen
RECOMMENDED OIL GRADE AND QUALITY	
Engine Oil	SAE10W30 API'SL'JASO'MA2' Grade upto ambient temperature of 5deg cel,2W30 or lower grades are recommended
Coolant	Ethylene glycol, distilled water 50:50 ratio per mixed
Brake Fluid	DOT3
Wind shield Washer	Distilled water
Grease	NLGI3
OTHERS	
Maximum speed	70Km/hr
Kerb weight	400Kg
Seat	4

3.4.2 Estimation of hybrid electric Bajaj Quet weight

The weight of a vehicle affects its driving characteristics range per charge and hill climbing capabilities. As more weight is added to the veicle the power train must over come larger forces. The forces which must be considered are rolling resistance, force of hill climbing and the force of liner acceleration. According to Argonne National Laboratory Transportation Technology R & D center, when vehicles are convereted to hybrid electric vehicle, their body and chassis weight is assumed to increase by 5% to account for any additional stractural strength needed to support the battery pack and power electronic components S.Plotkin et al (2001).So since the kerb weight of conventional Bajaj Qute is 400Kg the hybrid Bajaj Qute will be 5% more (i.e 420Kg)

3.4.3 Determining the wheel speed

The maximum velocity required on a lavel road is estimated to be 70km/hr (or 19.44m/s) just like the conventional type. The given wheel diameter from specification for conventional Bajaj Quet is 0.4938m, the linear velocity of the vehicle is determined by equation

$$v = r \times \omega_{rmax} \quad \text{………………………………………..(3.1)}$$

Where v is linear velocity of the vehicle

,r is radius of the wheel

ω_{rmax} is angular velocity of the wheel

Therefore $\omega_{rmax} = \frac{v}{r} = \frac{19.44}{0.2469} = 76.954 rad/sec$

$$N_{rmax} = \frac{60\times\omega_{rmax}}{2\pi} = \frac{60 \times 76.954}{2\times 3.141} = 734.997\ rpm$$

3.4.4 Calculation of DC motor Capacity

The motor is one of the core element of HEVs drive trains. The first step in creating appropriate system for the hybrid electric vehicle is to determine (or choose) the motor. In this thesis work a brushless DC motor is used for the choice of a motor the primary technical consideration to be taken are the speed, torque and power required by the load.

3.4.5 Determining the required power

When designing a vehicle, some of the most important design parameters those must be considered are like maximum speed (Vmax), maximum acceleration (a_{max}), etc, such important design parameters can be predicted from the vehicle dynamics. For example the maximum vehicle velocity (Vmax) is limited by the maximum power available at the wheels (Pwmax) the maximum vehicle acceleration (a_{max}) is limited by the maximum tractive force (Ftrmax) available at the driving wheels, the maximum tractive force in turn depends on the maximum torque available at the driving wheels (Twmax)

Generally the power required to drive a vehicle depends on the following factors.

- Rolling resistance of the tire on the road
- Aerodynamic drag force
- Inertial resistance in acceleration
- Gradient resistance
- Transmission losses.

Figure 11 Bajaj Qute, ***Bajaj Qute datasheet (2016)***

Power required to rotate the wheels is given by

$$P_{w\ @vmax} = R_t \times V_{ax} \quad \text{……………………………………..(3.2)}$$

Where $P_{w\ @vmax}$ $is\ power\ required\ by\ the\ wheel\ at\ maximum\ velocity$

R_t $is\ toal\ resistance$

V_{max} $is\ maximum\ velocity\ of\ the\ vehicle$

Since the total resistance of the vehicle is equal to tractive force the above equation can be writen as

$$P_{w\ @vmax} = F_t \times V_{max} \text{ ……………………………………..(3.3)}$$

Where F_t *is tractive force*

The tractive force is given by equation

$$F_{te} = F_{ad} + F_{rr} + F_{hc} + F_{la} + F_{wa} \text{ ………………….(3.4)}$$

Where F_{ad} *is aero dynamic force*

F_{rr} *is force of rolling resistance*

F_{hc} *is force of hill climbing*

F_{la} *is force of linear acceleration*

F_{wa} *is force of angular velocity*

It shall be noted that at maximum speed the force of linear and angular acceleration are zero, also the driving surface gradient at the maximum speed is zero degree so the above equation will be

$$F_{te} = F_{ad} + F_{rr}$$

The aerodynamic drag force is given by

$$F_{ad} = \frac{1}{2} \times \rho_a \times C_d \times A_{pf} \times V^2 \text{ ………………….(3.5)}$$

Where ρ_a *is density of air which is approximated* $\frac{1.22kg}{m^2}$ S. Plotkin et al (2001)

C_d *is coefficient of drag which is aproximated to be* 0.3 S. Plotkin et al (2001)

V *is speed of vehicle*

A_{pf} *is front projected area*

$$A_{pf} = SF * W * H \text{ ……………………………(3.6)}$$

Where

SF *is safety factor approximately between* 0.75 *to* 0.85 *in this project* 0.8 *is selected* Plotkin et al (2001)

W *is width of the vehicle equal to* $1.312m$

H *is heght of the vehicle equal to* $1.652m$

$$A_{pf} = 0.8 * 1.312 * 1.652 = 1.734m^2$$

$$F_{ad} = \frac{1}{2} \times \rho_a \times C_d \times A_{pf} \times V^2 = \frac{1}{2} * 1.225 * 0.3 * 1.706 * 19.44^2$$

$$= 120.45N$$

Force of rolling resistance depends on vehicle weight tires characteristic and the gravitational constant

$$F_{rr} = mg\mu_{rr} \text{ ....(3.7)}$$

Where

m $is\ mass\ of\ vehicle\ including\ driver\ and\ passenger\ which\ is\ assumed\ to\ be$ $800kg$

g $is\ gravitational\ acceleration$

μ_{rr} $is\ coefficient\ of\ friction\ which\ is\ equal\ to$ 0.02

$F_{rr} = mg\mu_{rr} = 800 * 9.81 * 0.02 = 156.96N$

The the tractive force will be

$F_{te} = F_{ad} + F_{rr} = 120.45 + 156.96 = 277.36N$

The power required at the wheel will be

$P_{w\ @vmax} = F_t \times V_{max} = 277.36 * 19.44$ = 5392.02 W

Hence the power required from the motor is given by

$$P_{mmax} = \frac{P_{wmax}}{\mu_t} \text{ ....(3.8)}$$

Where P_{mmax} $is\ maximum\ power\ required\ fro\ the\ motor$

μ_t $is\ transmission\ efficiency\ approximated\ to\ be$ 90% S. Plotkin et al (2001)

Hence

$$P_{mmax} = \frac{P_{wmax}}{\mu_t} = \frac{5392.02}{0.9} = 5991.14W \approx 6000W$$

Hence the maximum power required from DC motor to drive the hybrid electric bajaj on a level road at maximum velocity of 70km/hr is approximately 6 kW. Now inorder to select the DC motor that meet the functional requirement and the design prameter power torque and speed of the DC motor was calculated.

3.4.6 Determining DC motor speed

From the above callculation it is assumed that DC motor power is estimated to be 6 kW. Maximum angular velocity achived when no load is applied.

$$\omega_{max} = \frac{E_b}{k_b} \text{ ....(3.9)}$$

Where E_b $is\ back\ electro\ motive\ force\ in\ volt$

K_b $is\ electromotive\ force\ constant$

For the required DC motor in this project the back electromotive force constant (K_b) is given by the manufacturer and it is equal to 0.133.Back electormotive force is also given by equation.

$$E_b = V - I_a \times R_a \text{ ……………………………………..(3.10)}$$

Where $V\ is\ supplied\ voltage\ to\ DC\ motor\ from\ the\ battery\ in\ volt$

$I_a\ is\ armature\ current\ in\ ampere$

$R_a\ is\ armature\ resistance\ in\ ohoms$

To determine maximum current flow to the armature the following equation is used.

$$P_{in} = P_{dev} + P_1 \text{ ………………………………………(3.11)}$$

Where $P_{in}\ is\ power\ input\ from\ the\ battery\ in\ wat$

$P_{dev}\ is\ maximum\ power\ developed\ in\ watt$

$P_1\ is\ power\ loss\ in\ armature$

hence

$$V \times I_a = P_{dev} + R_a \times I_a^2 \text{ ……………………….……(3.12)}$$

$$V \times I_a = P_{dev} + percentage\ of\ loss\ \times P_{dev}$$

In this project, since the maximum power required from DC motor is 6000watt, minimum efficency required is 90%, so maximum power loss is 10%, the armature resistance is 0.256ohm and batterry voltage is 60V. Therfore the above equation will be;

$$V \times I_a = P_{dev} + percentage\ of\ loss\ \times P_{dev}$$

$$60 \times I_a = 6000 + 0.9 \times 6000$$

$$I_a = 110A$$

The maximum current required by DC motor to obtain maximum power is 110A

Then $E_b\ will\ be\ calculated\ as$

$$E_b = V - R_a \times I_a$$

$$E_b = 60 - 110 \times 0.256 = 31.84V$$

Finally the no load maximum angular velocity is calculated as

$$\omega_m = \frac{E_b}{K_b} = \frac{31.84}{0.133} = \frac{239.398rad}{sec}$$

$$N_m = \frac{60 \times \omega_m}{2\pi} = \frac{60\ \times 239.398}{2 \times 3.141} = 2286.08rpm$$

3.4.7 Determining DC motor torque

In order to compute the electric torque generated by the motor to start the vehicle from rest, first the total force exerted by the system on the motor needs to be calculated. The total force on the vehicle at rest is the friction force (Ff) which is given by C. Prajapati et al (2014).

$$F_f = \mu mg \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.13)$$

Where F_f $is\ friction\ force$

$\mu\ is\ coefficient\ of\ friction$

$m\ is\ mass\ of\ vehicle$

$g\ is\ gravitational\ acceleration$

The total wheel torque required to start the vehicle is given by

$$T_w = \ \mu mgr \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.14)$$

Where $r\ is\ radius\ of\ the\ tire\ equal\ to\ 0.2723m$

$T_w\ is\ wheel\ torque$

$m\ is\ \ mass\ of\ vehicle\ and\ mass\ of\ passengers\ together\ 800kg$

$$T_w = 0.22 * 800 * 0.2723 = 470.142Nm$$

The torque required by DC motor to start the vehicle from rest is

$T_1\ is\ number\ of\ teeth\ on\ the\ wheel\ axle$

$T_2\ is\ number\ of\ teeth\ on\ the\ ring\ gear$

$$T_m = T_w * \frac{T_1}{T_2} * \eta = 470.142 * 0.9 * \frac{1}{6} = 70.52Nm$$

3.4.8 The selected DC motor specification

The table given below shows specification of the DC motor. The specification describes the technical characteristics of DC motor and used in estimation of battery capacity as well as controller selection.

Table 3.2 DC motor specification

Parameters	Specifications
DC motor type	Brushless DC motor
Maximum power output	6 kW
Minimum peak torque at the start	70.52Nm
Maximum speed	2,286.08rpm
Maximum voltage	60v
Maximum current	110A
Minimum efficiency	90

Table 3.3 The power required at different velocity of Bajaj Qute was calculated from equation 3.2

Speed of vehicle (km/hr)	Speed of vehicle (m/s)	Power requaired (watt)
0	0	0
10	2.778	442.753
20	5.556	925.82
30	8.333	1489.29
40	11.111	2173.87
50	13.889	3019.693
60	16.667	4064.13
70	19.445	5,355.34

As it is shown in Figure12 below the speed versus power required at the wheel of hybrid bajaj Quet is drawn, they have a parabolic relation with each other.

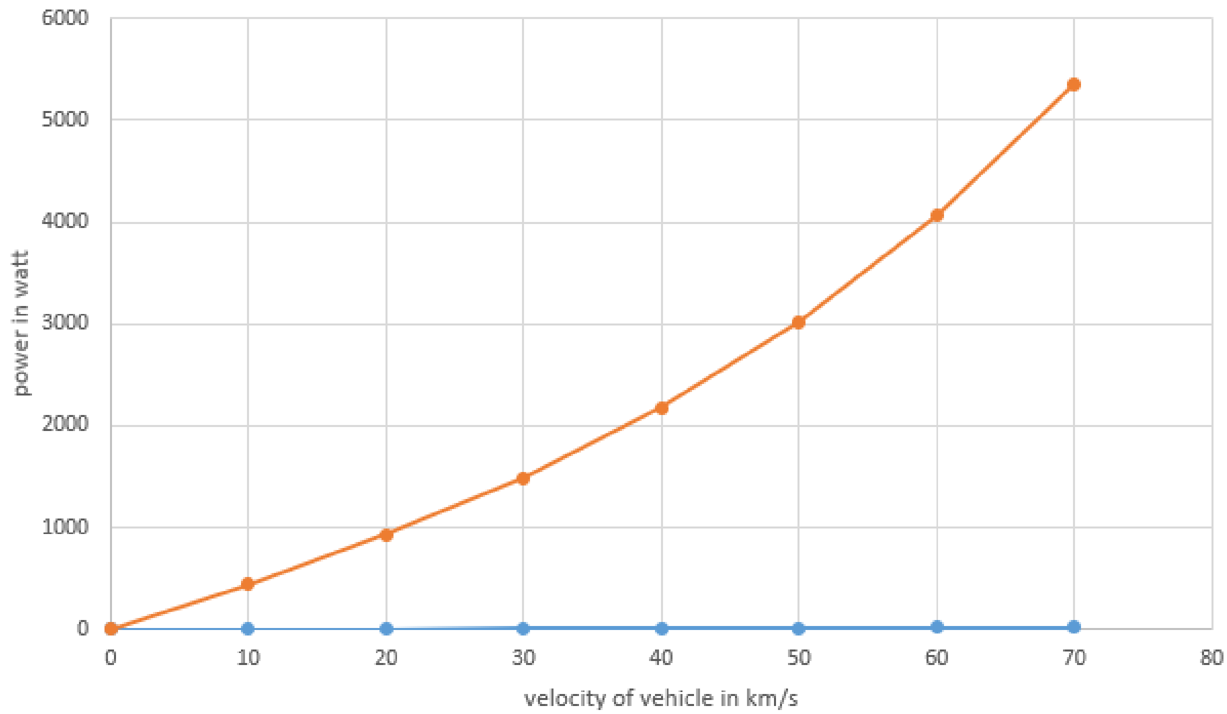

Figure 12 speed Vs power required of the vehicle

Table 3.4 Revolution of the wheel with its corresponding DC motor speed at different speed of HEV Bajaj Quet.

Speed of vehicle (km/hr)	Revolution of the wheel (Nw) (rpm)	Revolution of DC motor (N1) (rpm)
0	0	0
10	117.83	353.49
20	235.67	707.01
30	353.51	1060.53
40	471.44	1414.32
50	589.28	1767.84
60	707.12	2121.36
70	825.15	2475.45

As it is shown in Figure 13 below the revolution of the wheel Vs velocity of the vehicle in km/hr at different vehicle speed is shown.

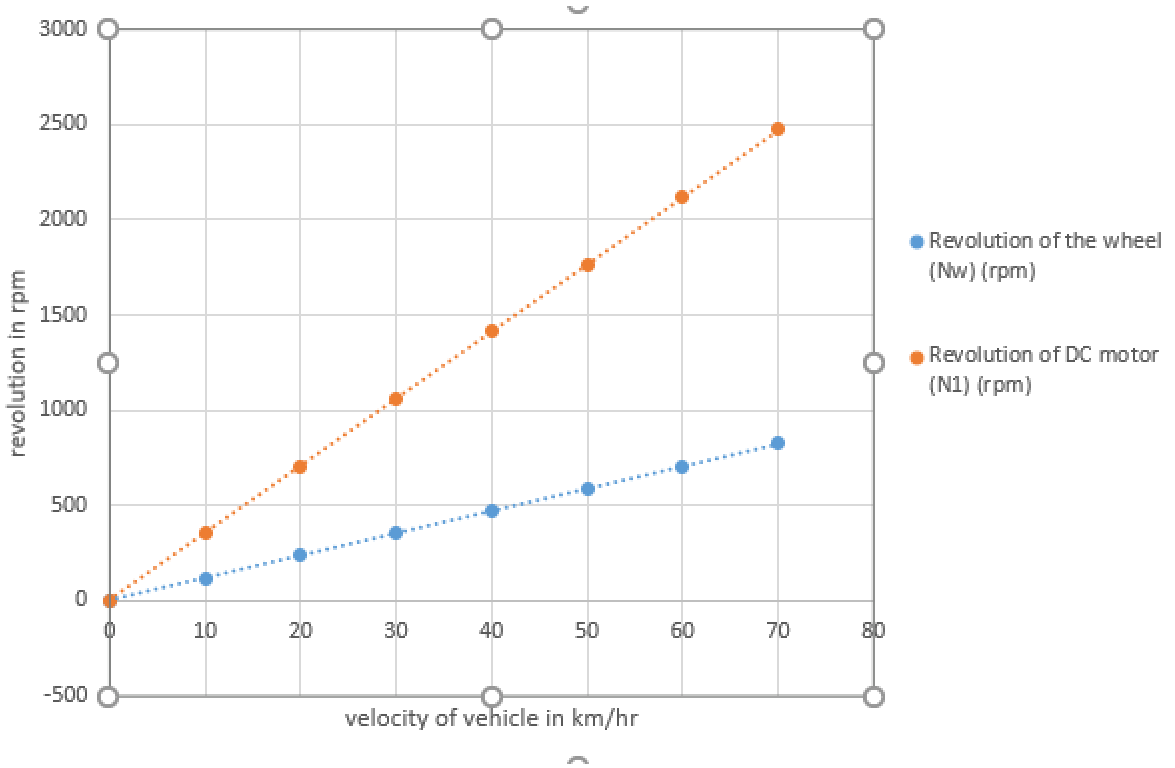

Figure 13 Revolution of the wheel Vs DC motor speed at different vehicle speed

3.5 Determining Battery Capacity

The battery chosen for this thesis was a high capacity lithium ion battery pack designed specifically for hybrid electric bajaj. The power required from the battery by DC motor was calculated as.

$$P_{batt} = \frac{P_{mmax}}{\eta_m} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.15)$$

Where P_{batt} *is power required from the battery*

P_{mmax} *is maximum power of DC motor*

η_m *is efficiency of DC motor*

$$P_{batt} = \frac{P_{mmax}}{\eta_m} = \frac{6000}{0.9} = 6666.66 watt$$

Therfore the power required by DC motor from battery is 6,666.66watt, but there is a light system accesoion such as head, tail, brake and turn signal light by assuming power required by lighting accessories is 100watt, hence maximum power required from battery is the sum of the two powers which is equal to 6766.66watt power is required from battery to drive the vehicle.

3.5.1 Determinig Battery voltage

The common nominal voltage of battery modules is 12v,24v36v,48v,60v,72v,84v,and 96v, for better energy storage and cost nominal voltage 60v was selected, the nominal voltage 60v is the industry's prefered standard voltage for different application christoper **M.simcoe, (2009).** The battery module shall therefore be rated 60v nominal voltage. It shall be small enough to fit on the orignal frame of Bajaj qute and capable of delivering sufficient current to the motor.

3.5.2 Determining Battery Capacity Rate (Crate)

Inorder to determine battery capacity rate (Crate) battery current and discharge time should be solved.

$$P_{batt} = V_{batt} \times I_{batt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.16)$$

Where V_{batt} $is\ battery\ nominal\ voltage$

I_{batt} $is\ battery\ current$

$$I_{batt} = \frac{P_{batt}}{V_{batt}} = \frac{6766.66}{60} = 112.77A$$

To operate DC motor and other electrical accessories at maximum power battery should supply continuously 112.77A current. Inorder to prolong the life of the battery it is recommended to operate the battery using only 60% of its capacity **Carl Vogel (2009).**

Therefore the minimum capacity of the battery is determined by dividing the required capacity by a factor of 0.6.

$$C_{rate} = P_{batt} \times \frac{T_{diss}}{0.6} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.17)$$

Where C_{rate} $is\ battery\ capacity\ rate$

P_{batt} $battery\ power$

T_{diss} $it\ time\ of\ dischare\ for\ the\ battery$

By assuming the battery should deliver or discharge continuously for two hours

$$C_{rate} = I_{batt} \times \frac{T_{diss}}{0.6} = 112.77 \times \frac{2}{0.6} = 375.9Ahr$$

Amper hour capacity is the amount of current that a battery can deliver for 2hr with out the cell voltage droping below 1.75volt with an electrolight temperature of 80^0 F Letman.s et al (2009).

Table 3.5 Specification for the proposed battery pack

S.No	Parameters	Battery size/specification
1	Battery type	Litium ion battery
2	System voltage	60V
3	Battery capacity	375.9Ahr
4	Maximum system current	112.77A
5	Total recharge time	8hr
6	Total hours of use	2hr
7	Battery power	6766.66watt

3.6 Planetary gear design

The power produced by two power plants may be coupled together by adding their speed. This is done with the help of planetary gear box or speed coupling devices as shown below. The Speed Coupler is a three port two degree-of-freedom device. Port 1 is a unidirectional input and Port 2 and 3 are bi-directional input or output, but both are not input at the same time. In case of HEV

- ✓ port 1 is connected to the shaft of an ICE directly or through a mechanical transmission.
- ✓ port 2 is connected to the shaft of an electric motor directly or through a mechanical transmission
- ✓ port 3 is connected to the driven wheels through a mechanical linkage

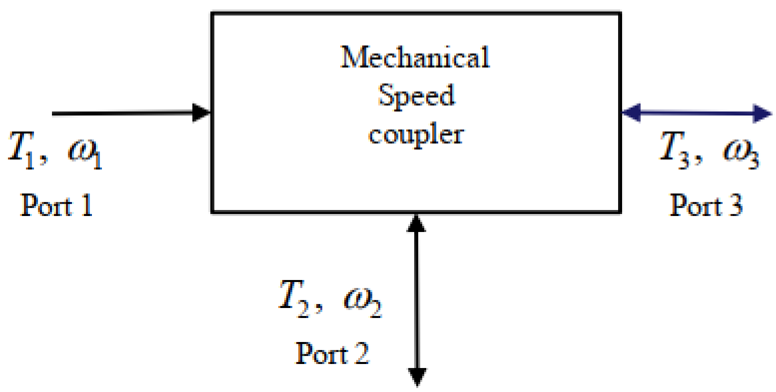

Figure 14 speed coupler S.Plotkin et al (2001)

For a losses speed coupler in steady state, the power input is always equal to the power output from it. For the speed coupler shown in Figure, the speed relation is given by.

$$\omega_3 = K_1\omega_1 + K_2\omega_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.18)}$$

Where K_1 *and* K_2 *are stractural parameters of speed coupler*

The planetary gear unit as shown in figure is a three-port device consisting of

- ✓ Sun gear, marked **1**
- ✓ Ring gear, marked **2**
- ✓ Carrier, marked **3**

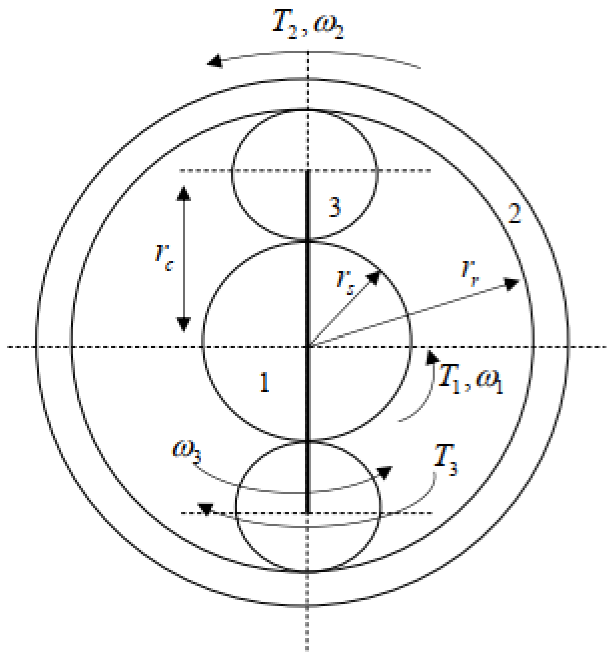

Figure 15 planetary gear front view S.Plotkin et al (2001)

For a planetary gear train configuration as shown in Figure, the gear ratio (r) is given by

$$r = \frac{\omega_1 - \omega_3}{\omega_2 - \omega_3} = \frac{z_2}{z_3} \times \frac{z_3}{z_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.19)}$$

$$r = \frac{z_2}{z_1} = \frac{r_2}{r_1}$$

Where ω_1 *angular speed of sun gear*

ω_2 *angular speed of ring gear*

ω_3 *angular speed of carrier*

z_1 *number of teeth on the sun gear*

z_2 $number\ of\ teeth\ on\ the\ ring\ gear$

z_2 $number\ of\ teeth\ on\ the\ carrier\ gear$

r_1 $radius\ of\ sun\ gear$

r_2 $radius\ of\ sun\ gear$

r_3 $radius\ of\ carrier\ gear$

The above equation can be expressed as

$$r(\omega_2 - \omega_3) = \omega_1 - \omega_3$$

$$\omega_1 - r\omega_2 - \omega_3(1 - r) = 0$$

$$\omega_3 = \frac{1}{1 - r} \times \omega_1 - \frac{r}{1 - r\omega_2}$$

In the analysis of the planetary gears, rotation and torque in the anticlockwise direction is assumed to be positive and in the clockwise direction is assumed to be negative. Using the power balance, the torque acting on each gear is obtained as

$$T_1\omega_1 + T_2\omega_2 + T_3\omega_3 = 0 \text{ ....(3.20)}$$

By substituting the value of ω_3 form the above equation

$$T_1\omega_1 + T_2\omega_2 + T_3(\frac{1}{1 - r} \times \omega_1 - \frac{r}{1 - r\omega_2}) = 0$$

$$T_3 = \frac{1 - r}{r} T_2$$

$$T_3 = -(1 - r)T_1$$

If the carrier is attached to a stationary frame (ω_3) then from equation above

$$r = \frac{\omega_1}{\omega_2} = -\frac{z_2}{z_1} = -\frac{r_2}{r_1}$$

$$T_1 = -\frac{\omega_2}{\omega_1}T_2$$

$$T_1 = -\frac{T_2}{r}$$

So, since speed of the engine from the specification $\omega_3 = 5500rpm$ and speed of motor generator two $\omega_2 = 2280rpm$ are known and gear ratio is assumed to be 2 the speed of motor generator one can be calculated as S.Plotkin et al (2001).

$$\omega_3 = \frac{1}{1-r} \times \omega_1 - \frac{r}{1-r}\omega_2$$

$$5500 = \frac{1}{1-2}\omega_1 - \frac{2}{1-2}2280$$

$$\omega_1 = -940rpm$$

$$T_1 = -\frac{T_2}{r} = \frac{70.52}{2} = 35.26Nm$$

3.7 Operating cost of hybrid Bajaj Qute

When considering the operating cost of a hybrid electric Bajaj Qute, there are two types of operating costs. The first is the electricity cost of charging the batteries. In this project, it is assumed that the baterry would be charged by using electricity from the grid in addition to regenerative baraking.

The second operating cost is made up of replacing the batteries spread out over their lifecycle assuming 2000cycle life of the lithium ion batteries, when estimated four year usage depending on riding frequency. The battery pack cost of 4500 would be spread over the mileage span of those 4years.

1. Determining the charging cost per day

$$C_{day} = \frac{IvtC_c}{1000} \text{……………………………………………(3.21)}$$

Where C_{day} $is\ charging\ cost\ per\ day$

$I\ is\ charging\ current\ in\ ampere$

$v\ is\ charging\ voltage\ in\ volt$

$$t\ is\ charging\ time\ per\ day\ in\ hour$$

$$C_c\ is\ charging\ cost\ of\ one\ kwhr\ in\ Birr = 0.5 birr\ according\ to\ ELPA$$

In this project once the battery is fully charged the EMC could travel 60km and it takes maximum 4hours to recharge those batteries

$$C_{day} = \frac{IvtC_c}{1000} = \frac{2.25 \times 220 \times 4 \times 0.5}{1000}$$

$$C_{day} = 0.99 birr/day$$

$$C_{km} = \frac{C_{day}}{60} = 0.017 birr/km$$

2. Determining charging cost per month

$$C_{month} = C_c \times day\ per\ month$$

$$C_{day} = 0.99 \times 30 = 29.4$$

3. Determining battery cost per day

The operating cost is made up of replacing the batteries spread out over their lifecycle. In this project the batteries are assumed to be recharged once per day. Since the life cycle of lithium ion batteries are greater than 2000 and the cost of those batteries are 4500 birr when estimated for four year usage depending on riding frequency. The operating cost of replacing the batteries spread out over the life cycle per day was calculated as equation.

$$B_c = \frac{cost\ of\ battery\ pack}{life\ cycle} \quad \text{.......................................(3.22)}$$

When $B_c\ is\ cost\ of\ battery\ pack\ per\ day$

$$B_c = \frac{cost\ of\ battery\ pack}{life\ cycle} = \frac{4500}{2000} = 2.25 birr/day$$

4. Determining total operating cost of Bajaj Qute per month

$$C_t = (C_{day} + B_c)30 \quad \text{...................................... (3.23)}$$

Where C_t is total operating cost

$$C_t = (0.99 + 2.25)30 = 97.2\ birr\ per\ month$$

3.8 Operating cost of conventional Bajaj Qute

Cost per day to operate an equivalent gasoline Bajaj Qute for 60km was calculated as follow.

$$C_{dayconven} = fuel\ consuption\ in\ liter \times gasoline\ cost\ per\ liter$$

$$C_{dayconv} = 2 \times 22 = 44 birr\ per\ day$$

So to drive conventional Bajaj Qute for 60km per day the operating cost would be 44birr.

3.9 Simulation model blocks

3.9.1 Motor model

The motor provides rotary motion and when coupled with wheels or drums and cables it can provide translational motion. In this model the input of the system is the voltage source applied to the motor armature while the output is the rotational speed of the shaft, armature current and electrical torque. The rotor and shaft are assumed to be rigid. The motor model includes some terms and parameters for power loss and time lag while other terms were omitted from the model. The model accounts for power loss in the winding resistance and time lag due to the energy storage in the magnetic field of the winding inductance. There is no field power loss because it is a permanent magnet field. The motor model block is shown in Figure 16 below.

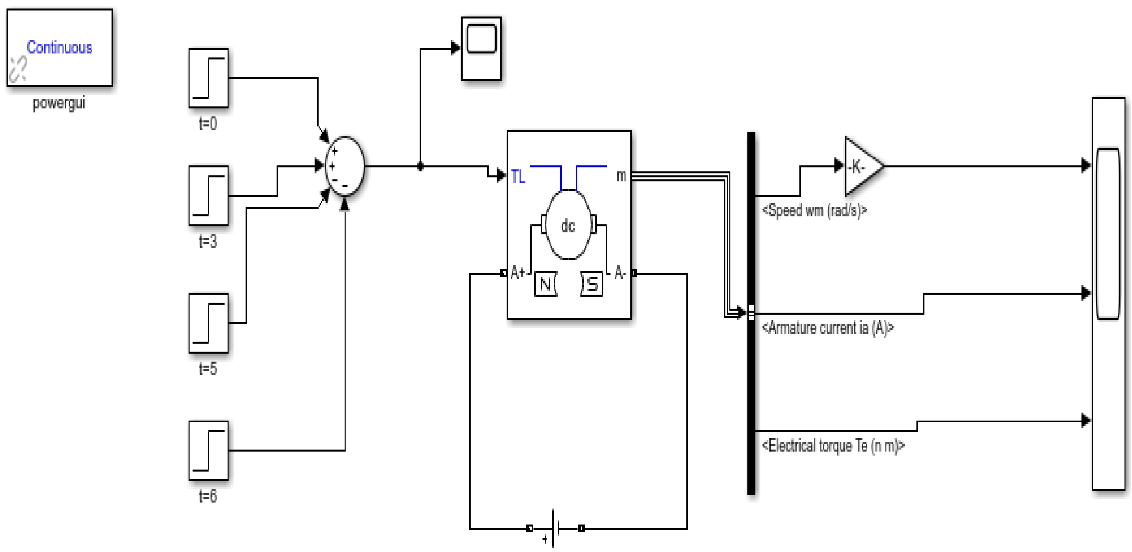

Figure 16 motor model

The shaft output torque is equal to developed torque minus friction loss and inertia losses are assumed to be zero, the developed torque and output torque are equal in this model.

3.9.2 Battery model

Battery is modeled as a voltage source with an internal resistance. The model accounts for internal power loss in the resistance of the battery. The battery is assumed to have a constant internal voltage source. The battery terminal voltage is equal to the sum of internal voltage and resistance voltage drop. The battery voltage and battery current are equal to the controller low side voltage and current. The battery model has different modes when charging and discharging. Load signal is provided when discharging while power source signal is provided when charging as shown in figure 17 below.

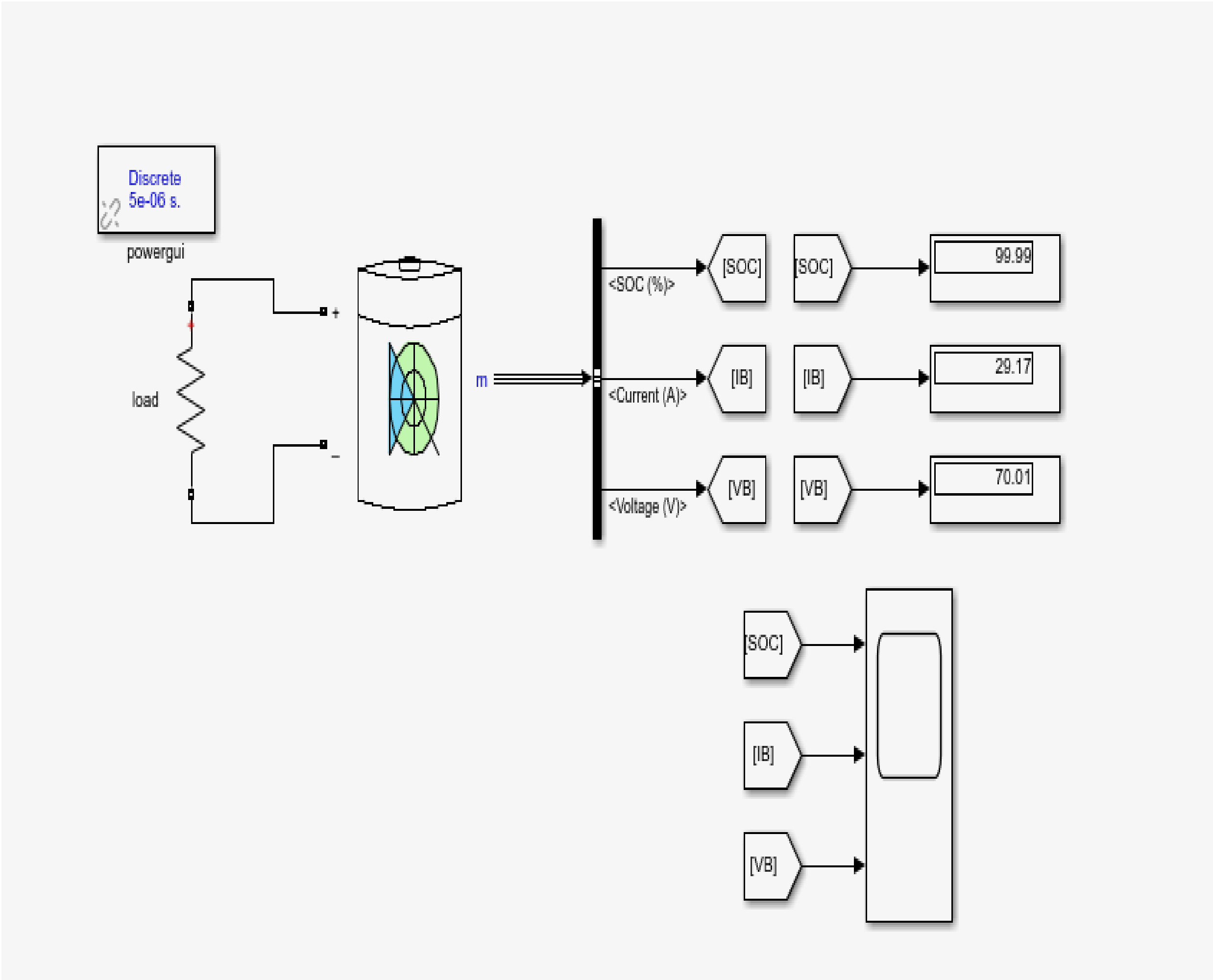

Figure 17 Battery discharging mode

As it is shown in Figure 17 battery discharging model is created by using MATLAB Simulink. The load signal is provided to the battery which represents motor in the real world and the SOC (state of charge) effect is observed from the scope.

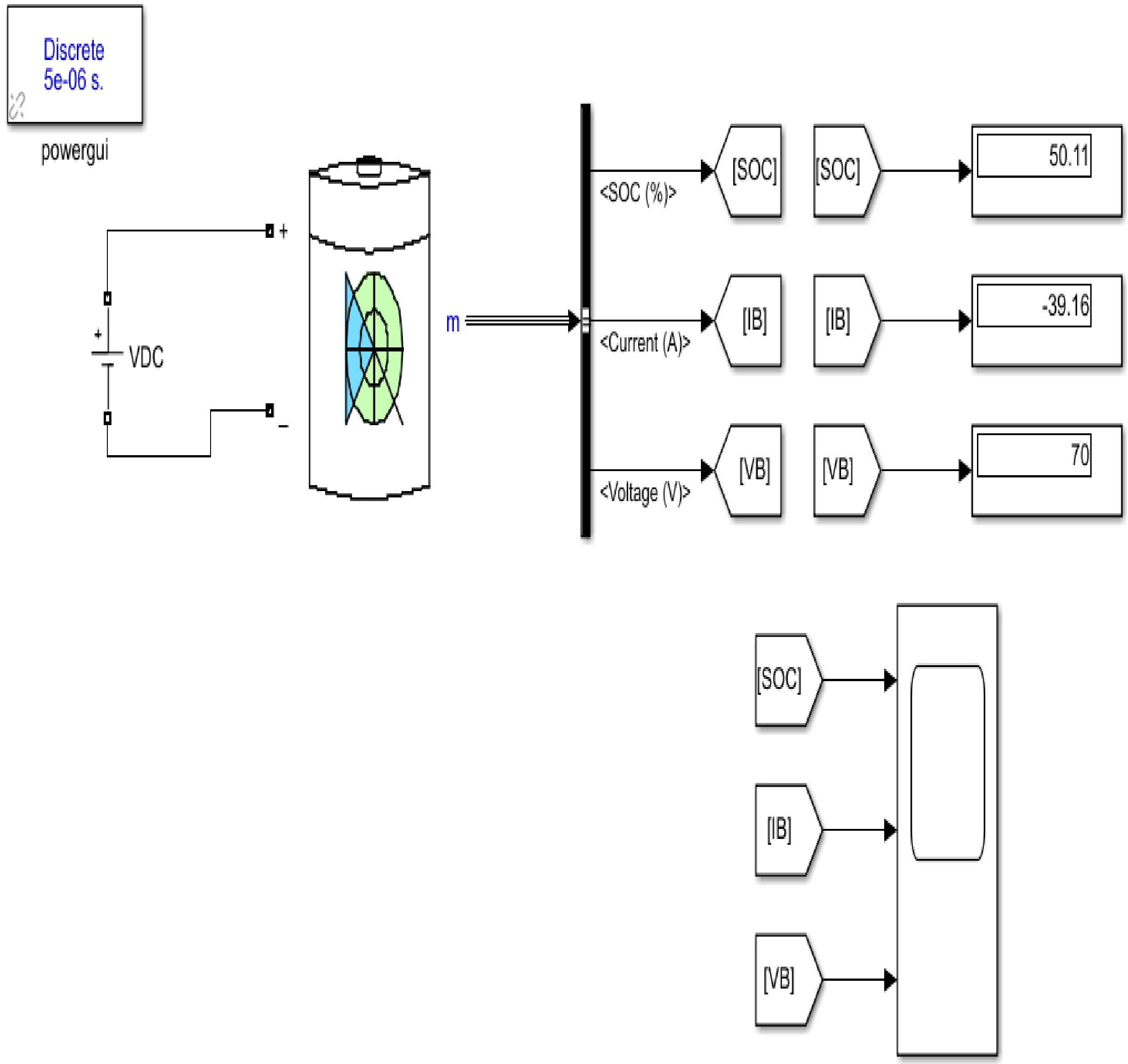

Figure 18 Battery charging mode

In Figure 18 battery charging model is created by using MATLAB Simulink. Voltage signal is provided to the battery which represents regenerative braking or grid power supply in the real world as its effect is observed from the scope.

3.9.3 DC/DC converter model

As it is discussed earlier DC/DC converter is designed for a wide range of input voltage. As it is likely for multiple voltages to exist in HEV's DC/DC convertor have to be used. DC/DC convertor is modeled as shown below in Figure 19.

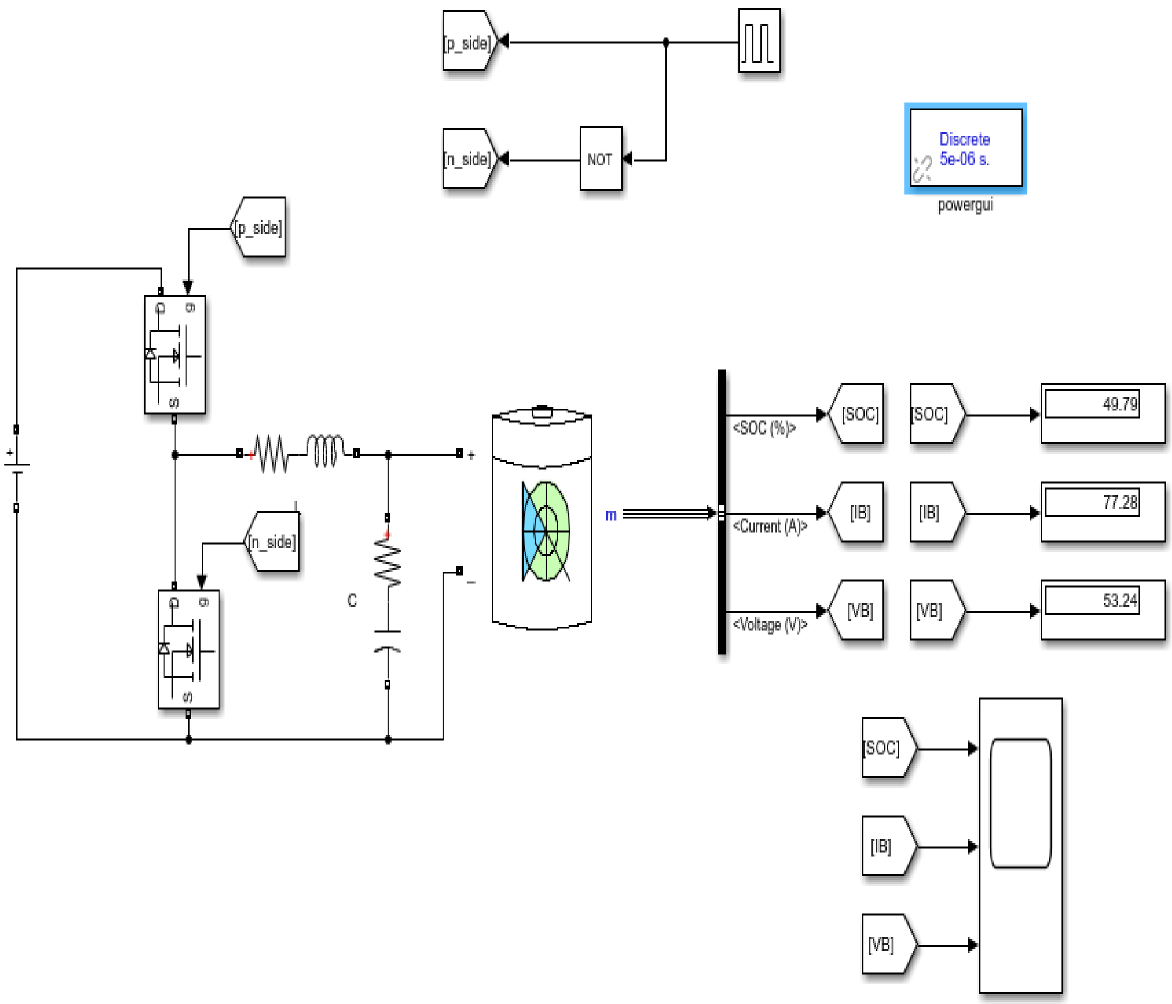

Figure 19 DC/DC convertor model

In DC/DC convertor MATLAB Simulink model shown in figure 19 battery is connected to two IGBT/ insulated gate bipolar transistor diode which are used in voltage source conversion.

3.9.4 Regenerative system modeling

Regenerative braking is an energy recovery mechanism which slows a vehicle by converting its kinetic energy in to a form which can be either used immediately or stored until needed. Regenerative braking system is modeled as shown below.

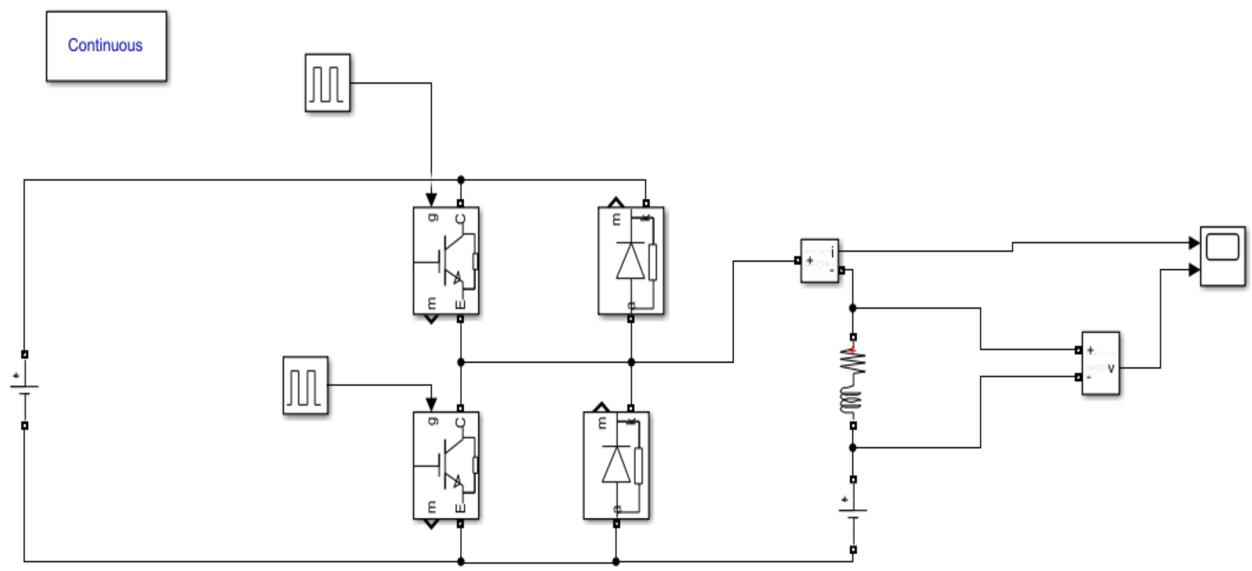

Figure 20 Regenerative braking model

Regenerative braking model shown in Figure 20 shows two IGBT and Mosfet diodes and pulse generators are used for the conversion of kinetic energy power to battery charging power.

3.9.5 Conventional Bajaj Qute Model

This Simulink model is developed to show the conventional Bajaj Qute drive train. The components which are used to develop this model are existent in all combustion engine vehicles. As it is shown in the model the vehicle is driven by its rear wheels. This model consists only of the components, that are required to make the basic vehicle model work/ or move.

The torque generated by the prime mover is sent to the torque convertor which in turn transfers it to the gear box. The differential connected to the gear box splits the in coming torque equally in to the two wheels.

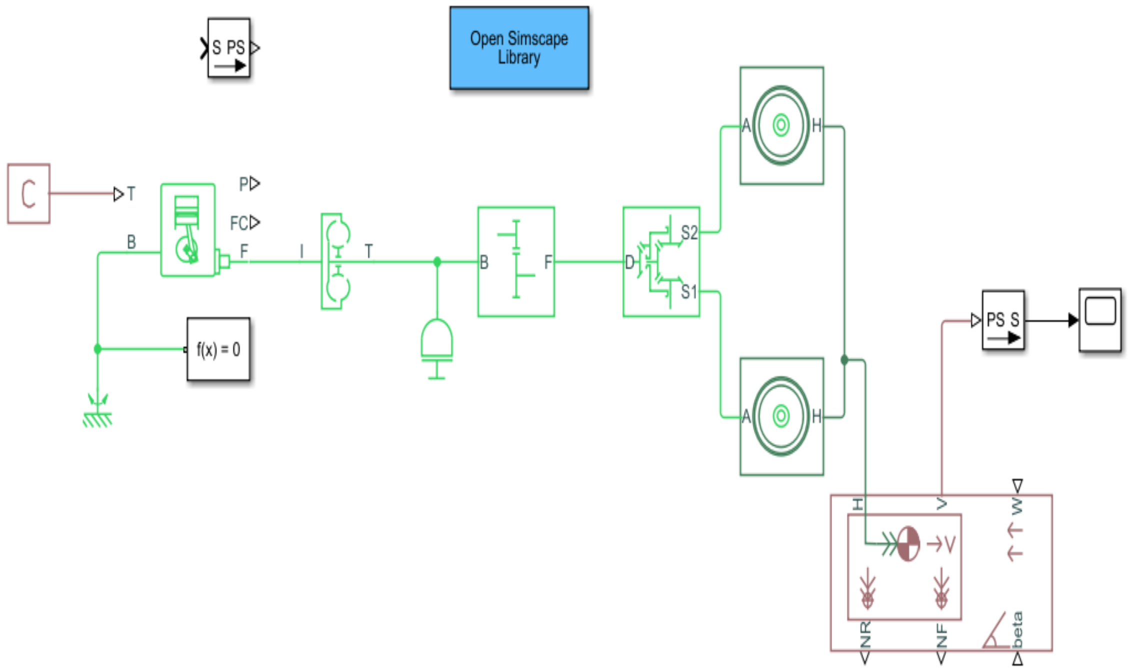

Figure 21 Conventional Bajaj Quet model

MATLAB Simulink model for conventional gasoline Bajaj Quet model is shown in figure 21, as it is shown in the model engine is connected to the differential via torque convertor, differential is connected to the wheel and finally the wheel to the vehicle body.

3.9.6 HEV Bajaj Qute Model

This model shows drive train of hybrid electric Bajaj Qute. The components which are used for the conventional Bajaj are used and some components are added like, motor, generator, battery and DC/DC convertor.

In this model the torque generated by the prime mover or engine is sent to the torque convertor, which in turn transfers it to the planetary gear box. Since the gear box is planetary gear box torque from the engine is connected to carrier gear torque from motor generator one is connected to sun gear and motor generator two is connected to ring gear of planetary gear. Finaly the wheel is driven by the differential.

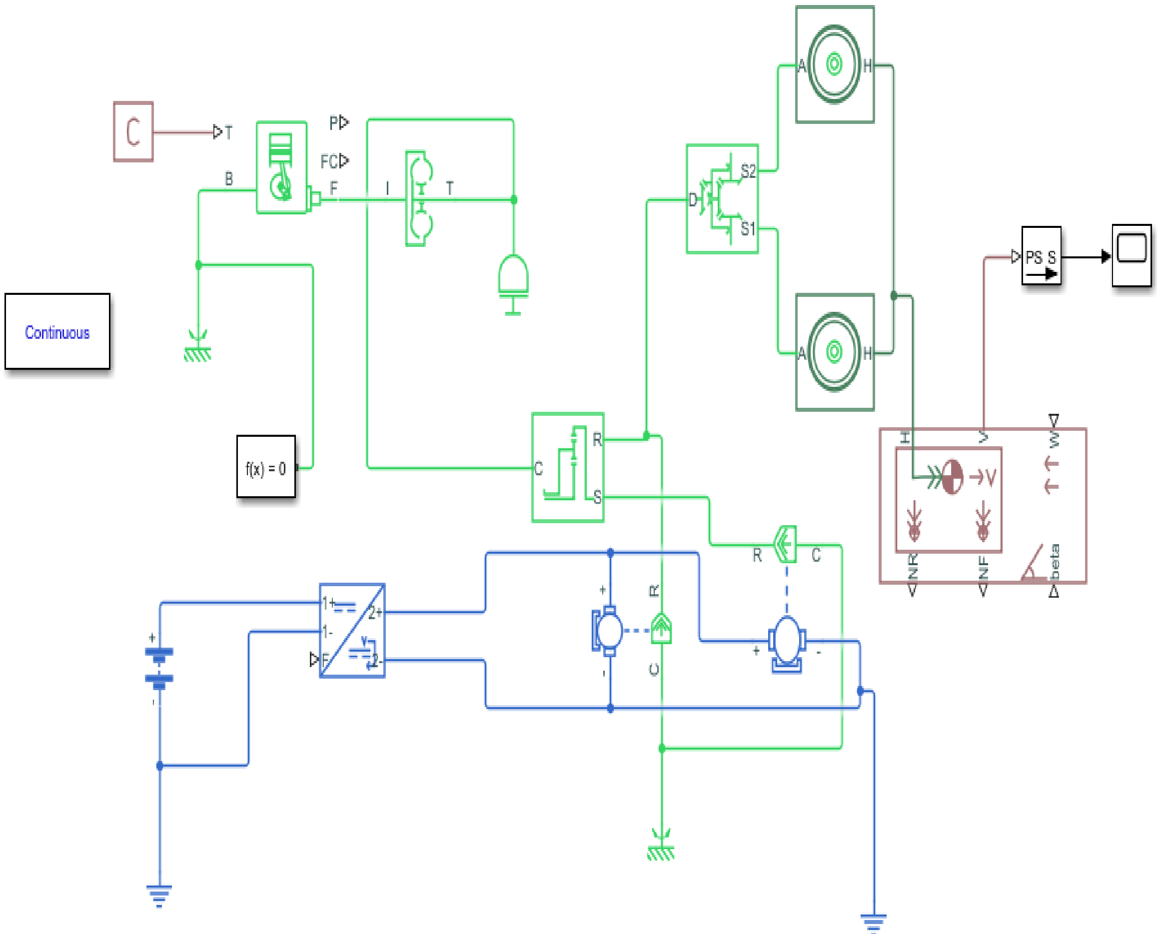

Figure 22 Hybrid Bajaj Qute model

MATLAB Simulink model for hybrid Bajaj Quet model is shown in Figure 22. The model includes an additional component like planetary gear set, motor, generator battery and DC/DC convertor which is not there in the conventional Bajaj Quet model.

CHAPTER FOUR

SIMULATION RESULT AND DISCUSSION

The purpose of this thesis work is to model a hybrid electric Bajaj Qute and compare it with the conventional Bajaj Qute. The simulation is shown on the motor/generator, DC/DC convertor, Battery, Regenerative braking and over all vehicle drive train.

Table 4.1 HEV specification

Component	Model
Motor Generator1	5kW
Motor Generator2	6.7kW
Energy storage	6.7kW li-ion
Engine	9.9 kW @ 5500+250rpm
Gearbox	Planetary

The components in table 4.1 and their model it taken from the Bajaj Quet brousher and from calculation done in the privious chapter

Table 4.2 Conventional vehicle specification

Component	Model
Engine	9.9kw
Gear box	Constant mesh manual gear box
Max speed	70km/hr

4.1 Motor current, speed and torque

The motor used in this thesis work is a brushless DC motor which gets its power from the battery. As it is shown below in figure 23 motor current and torque follow each other. This relationship reflects the torque equation that were discussed earlier. It is also shown that the motor torque and speed curves are inversly related that is as the speed decreases the torque will increase. From the simulation result we can also see that the torque generated by DC motor is proportional to the armature current and the strength of the magnetic field.

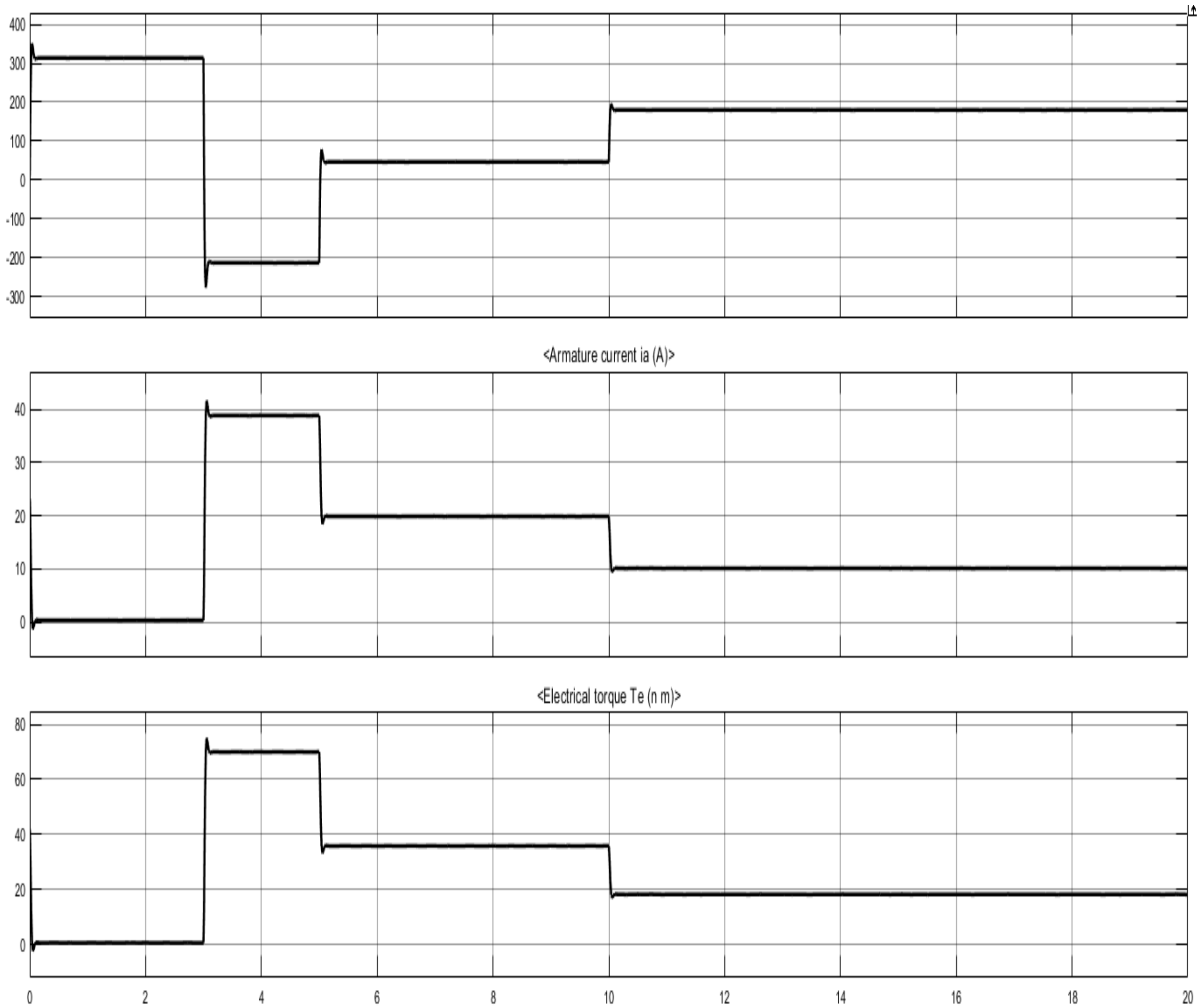

Figure 23 Motor current, speed and torque

The result observed from figure 23 is that the torque developed will have an inverse relation to the speed of the vehicle and it is directly related to armature current.

4.2 Battery SOC, current and voltage during discharging

During discharge/or when the motor draws power from the battery as shown below in figure 24, the state of charge will reduce, as voltage and current are being supplied constantly. This reduction in state of charge indicates that the the power is being delivered to the motor generator and the vehicle is moving.

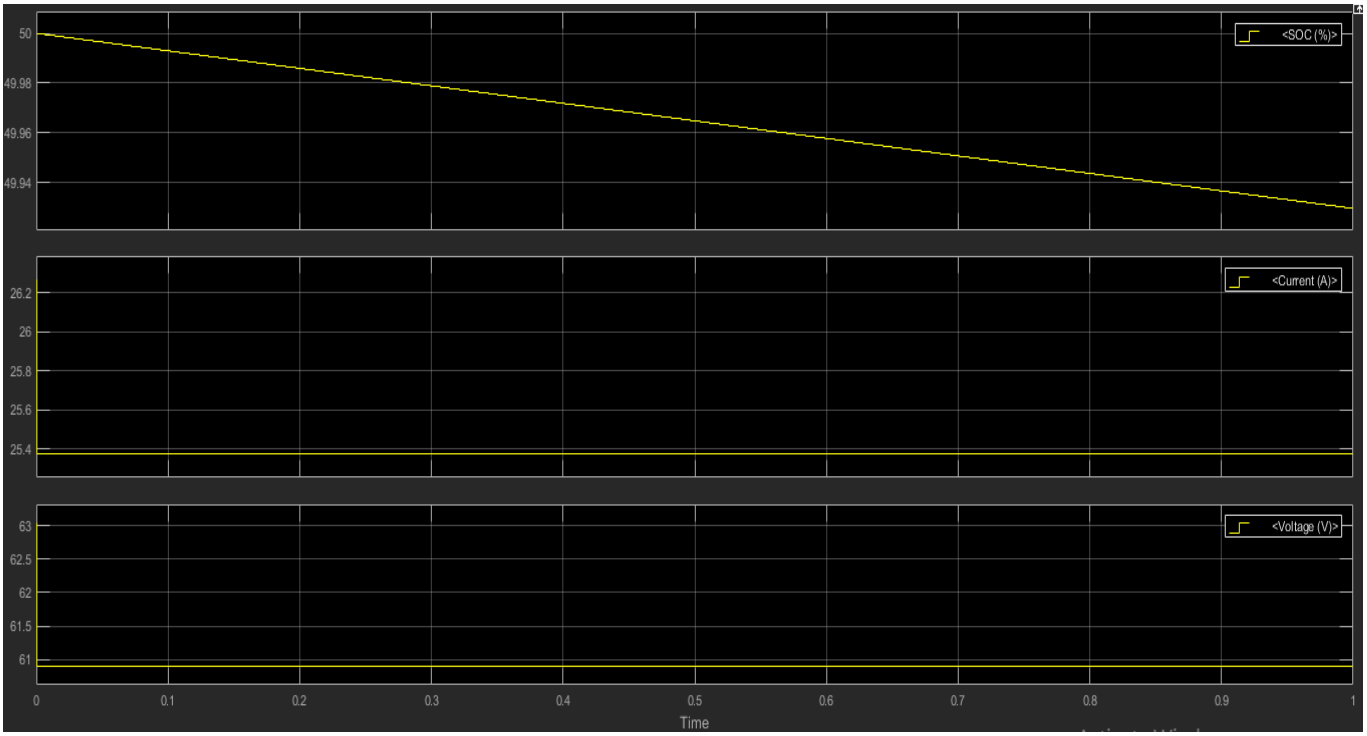

Figure 24 Battery SOC, current and voltage during discharging

4.3 Battery SOC, current and voltage during discarging

The opposite of discharging happens when charging the SOC will increase during charging and constant voltage is being supplied to the battery. In figure 25 it is shown that the battry is getting charged.

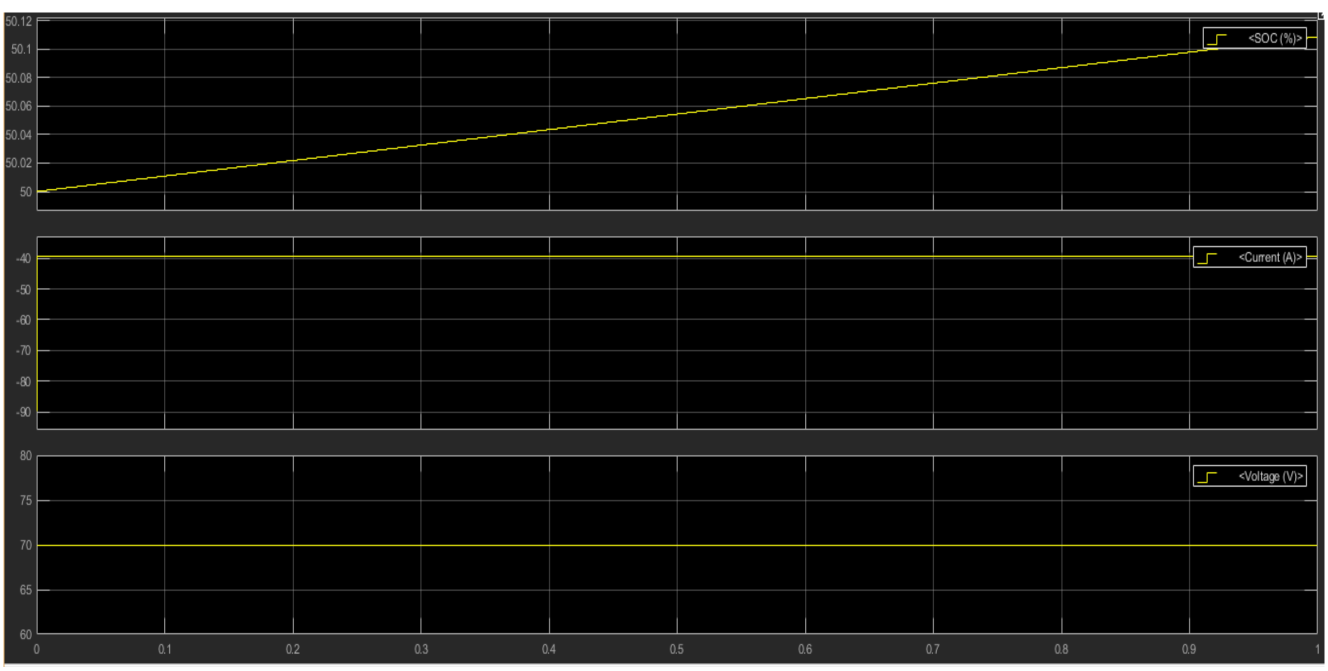

Figure 25 Battery SOC, current and voltage during discharging

4.4 Charge control with bidirectional DC/DC converter

DC/DC electrical energy conversion alters the voltage of a DC power source from one level to an other level. From the result it can be observed that the current will change with duty change, that is when motoring and regeneration, also the result shows that charging and discharging mode is working.

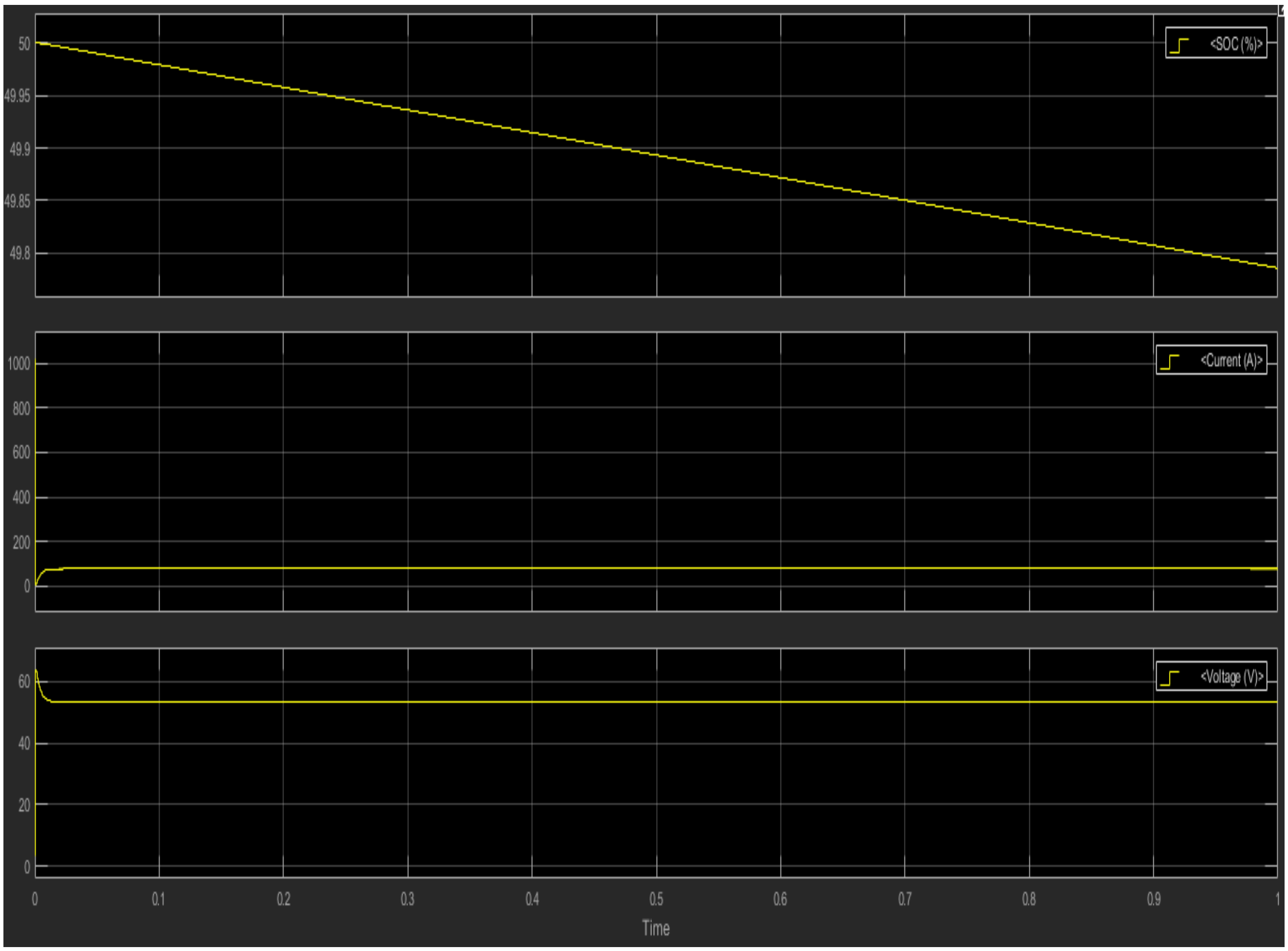

Figure 26 Charge control with bidirectional DC/DC converter

4.5 Current and voltage during motoring and regeneration

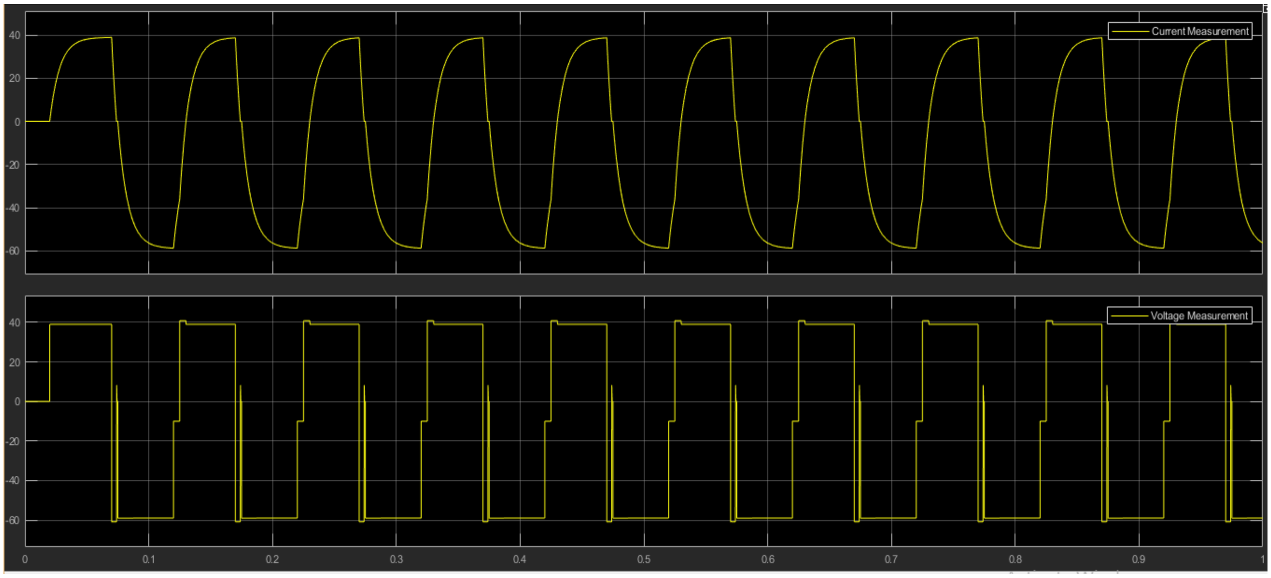

Figure 27 Current and voltage during motoring and regeneration

As it can be seen from the simulation result during motoring current and voltage value will raise indicating that power is being supplied to the motor. When the vehicle is in breaking mode current and voltage value become negative indicating that the electrons are flowing to the battery/ or is charging the battery.

4.6 Speed and fuel consumption response of Conventional Bajaj Model

From the responses derived from the simulation it is observable that the maximum speed attained in the model is 19m/s at full throttle. The speed result is almost the same as the actual Bajaj Quet. The fuel consumed in the given simulation time is 2.7×10^{-3} kg/s.

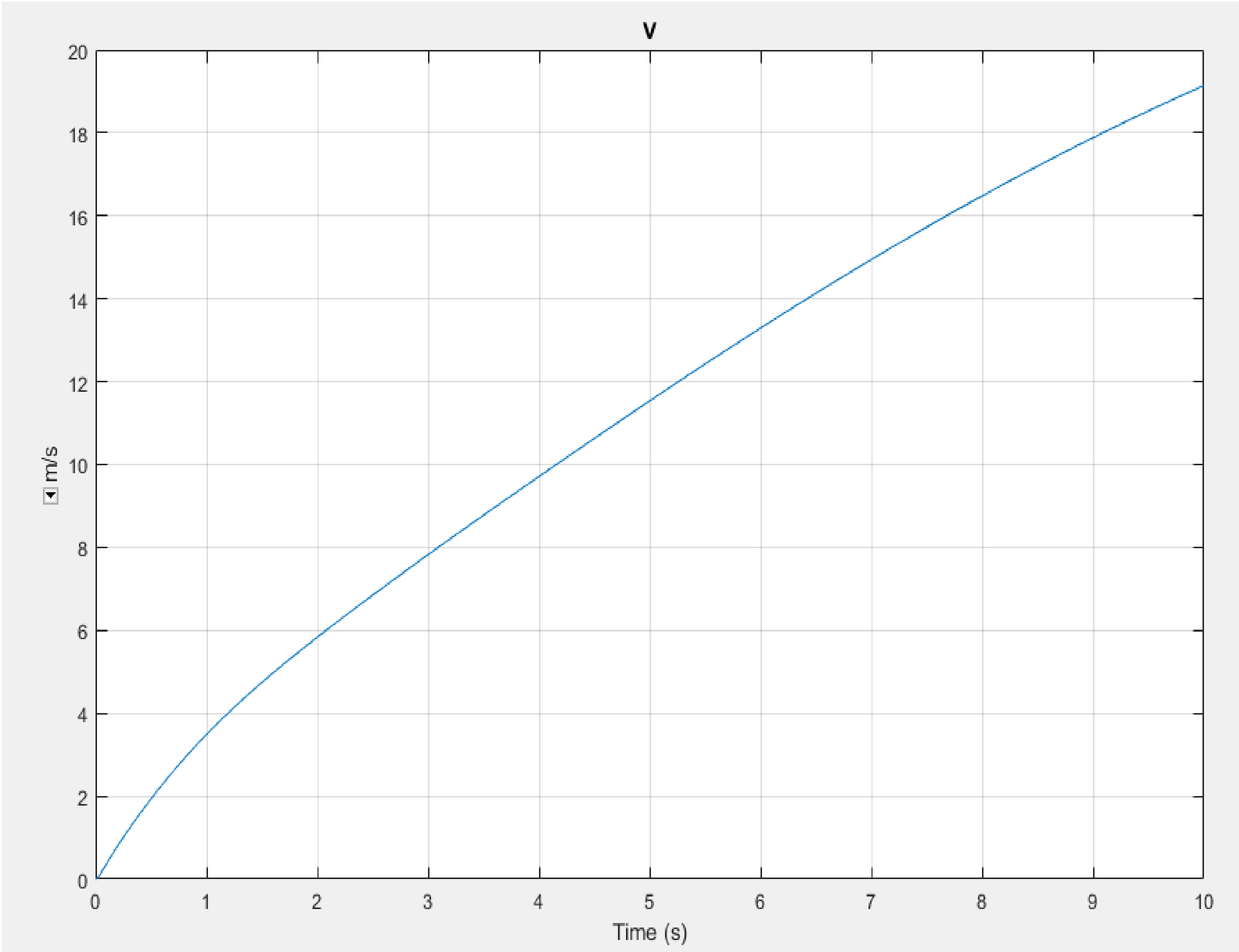

Figure 28 Speed Vs time response of conventional Bajaj Quet

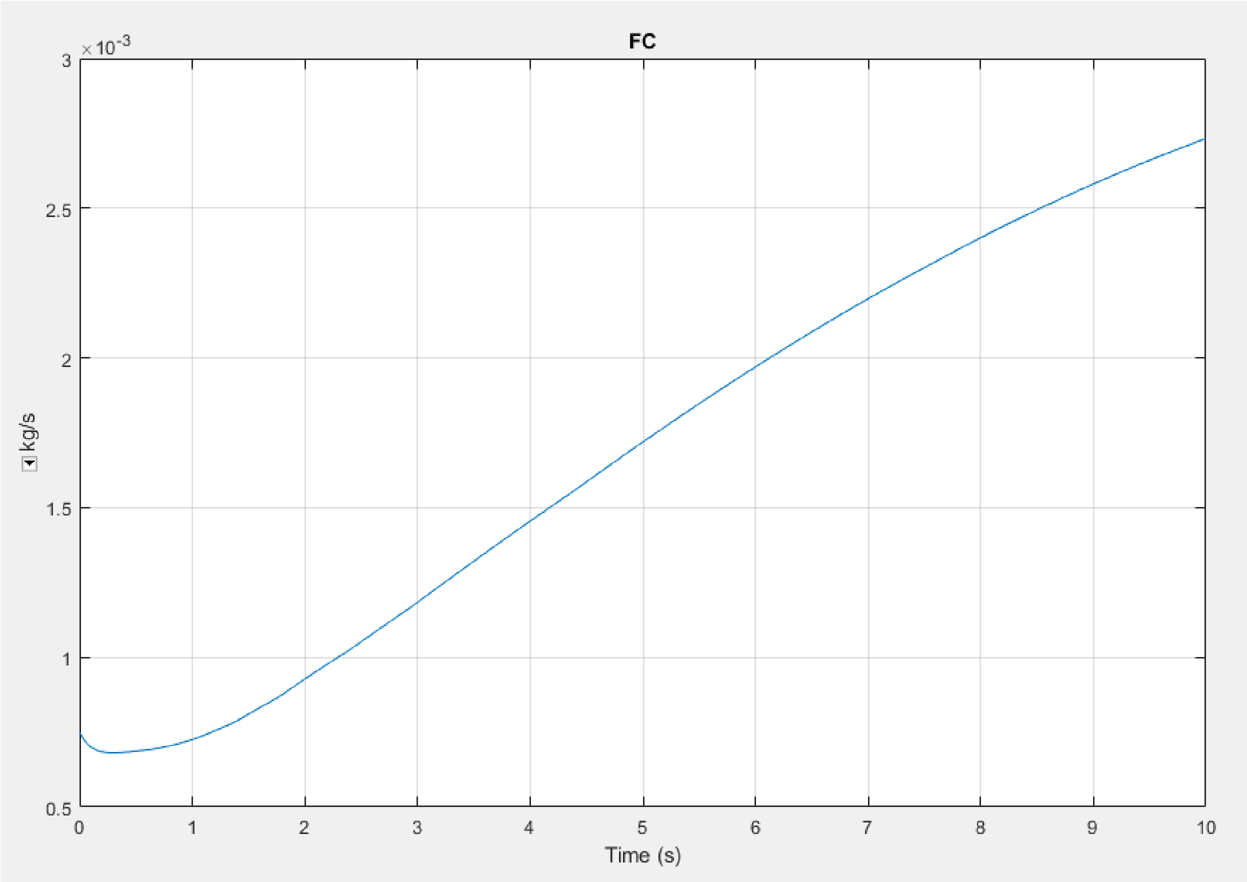

Figure 29 Fuel consumption Vs time response

4.7 Speed and fuel consumption response of HEV model

MATLAB Simulink simulation response of hybrid Bajaj Quet shows that the maximum speed attained in the model is 32m/s at full throttle which is higher than the conventional vehicle. The fuel consumed in the given simulation time is 2.1×10^{-3} kg/s which shows lesser fuel consumption than the conventional model.

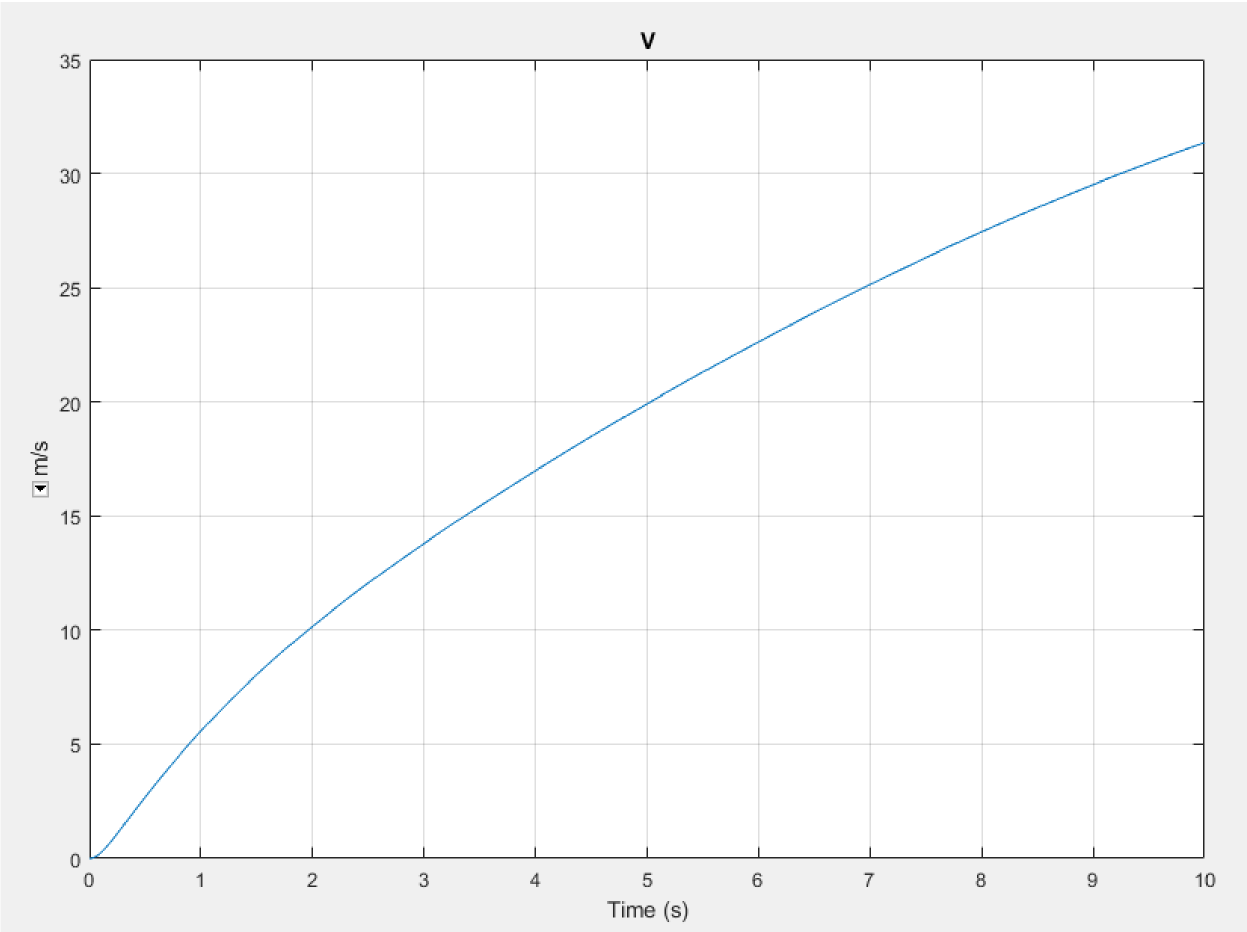

Figure 30 Speed Vs time response of HEV Bajaj Quet

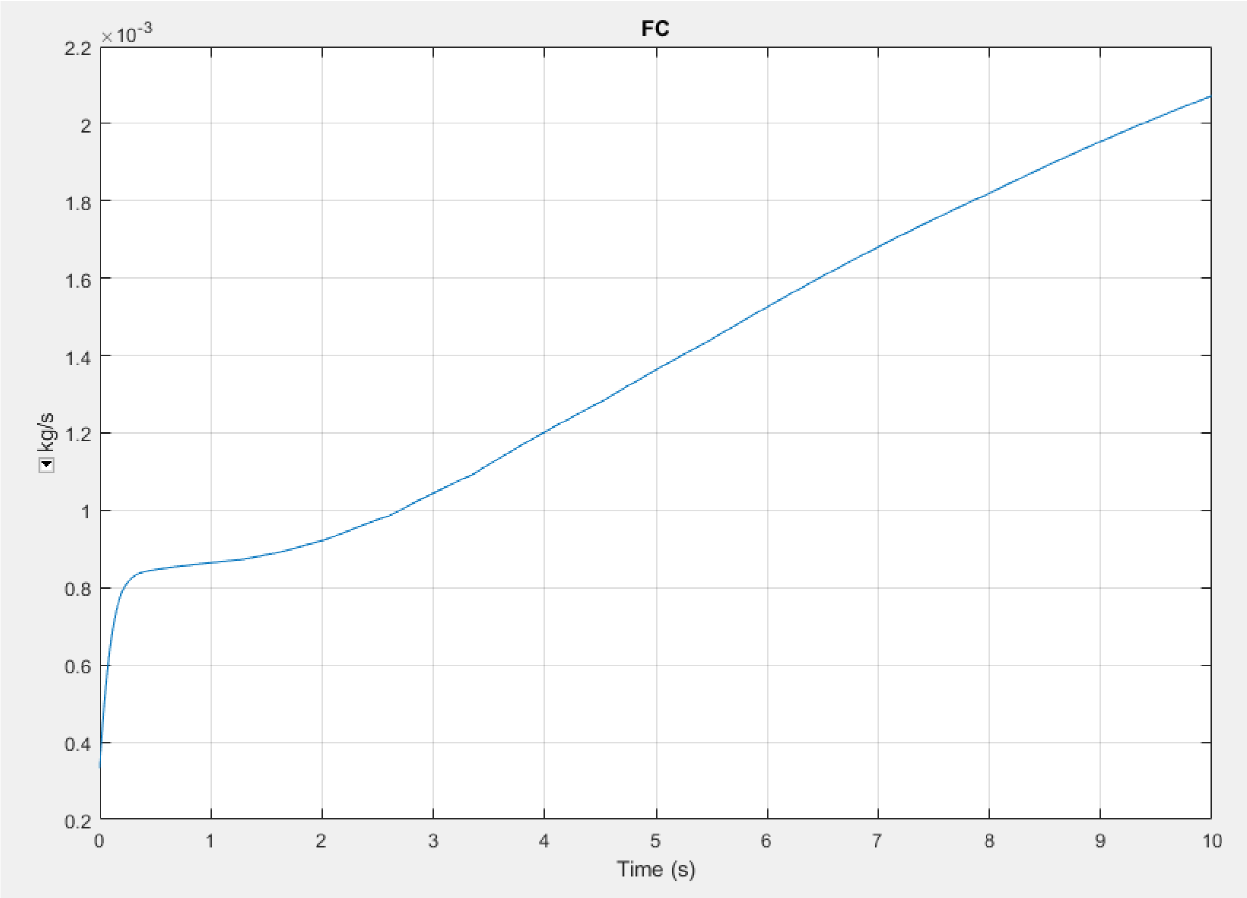

Figure 31 Fuel consumption Vs time response of HEV Bajaj Quet

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Summary

The aim of this graduation thesis is to compare a hybrid and conventional Bajaj Quet, and show the difference in fuel consumption and speed. The thesis first modeled the components of the hybrid vehicle and finally the whole transmission of both hybrid and conventional vehicle was modeled. The result of the experiment shows that hybrid Bajaj Quet shows lesser fuel consumption and higher speed than the conventional one. Finally, to summarize

1. MATLAB/Simulink model was created for motor which shows angular speed, armature current and torque.
2. MATLAB/Simulink model for battery indicates SOC (or state of chare), current and voltage for both charging and discharging mode.
3. MATLAB/Simulink DC/DC convertor model indicating SOC (or state of charge), current and voltage was developed.
4. MATLAB/Simulink regenerative braking model showing current and voltage during motoring and regeneration was developed.
5. Conventional and hybrid vehicle MATLAB/Simulink model indicating the speed and fuel consumption was developed.

5.2 Conclusion

In this dissertation a four-wheeler Bajaj Quet power train is modeled, both as a conventional and hybrid mode by using MATLAB/Simulink environment. The speed and fuel consumption profiles from the simulation have been compared. The paper also focusses on determining general specification of hybrid Bajaj Quet. It also included modeling of parts motor, battery, DC/DC convertors and motoring and regenerative braking systems.

To sum up, when modeling the choice of components must be selected according to the type of structure and level of hybridization. The result shows an improvement in the fuel consumption and speed of the hybrid Bajaj Quet over the conventional one.

5.3 Recommendation

The key recommendation from this study is that the HEV model developed in chapter three should be the starting point for further construction and prototyping of the transmission system. Also, in further development process the simple planetary gear power train should be modified to two or three planetary gear sets.

Some parts in the transmission can still be improved. This thesis already demonstrated that speed and fuel consumption are improved by adding battery, motor and convertor, fuel consumption will also be reduced by downsizing the engine which makes the transmission heavier.

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APPENDIX A

This section contains information of the simulation model setup as described in section 3.7

1. Simulink to PS converter: This block converts the dimensionless input signal to a Physical Signal that can be used by a block that takes physical signals as inputs.

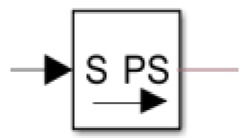


Figure 32 S-PS Converter

The unit expression in 'Input signal unit' parameter is associated with the dimensionless input signal. The desired unit can be assigned to the Physical Signal

2. PS to Simulink converter: This block converts the input Physical Signal to a dimensionless output signal.

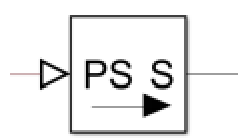


Figure 33 PS-S Converter

The unit expression in 'Output signal unit' parameter must match with the unit of the Physical Signal and determines the conversion from the Physical Signal to the dimensionless output signal

3. Engine: Represents a system-level model of a spark ignition engine. A spark-ignition engine generally refers to a petrol engine. In this type of engines, the air-fuel mixture in the combustion chamber is ignited by a spark generated by the spark plug. Bajaj Qute uses petrol as fuel. The engine is the prime mover, as the fuel is converted to mechanical energy is this component. The

throttle input signal T lies between zero and one and specifies the torque demanded from the engine as a fraction of the maximum possible torque.

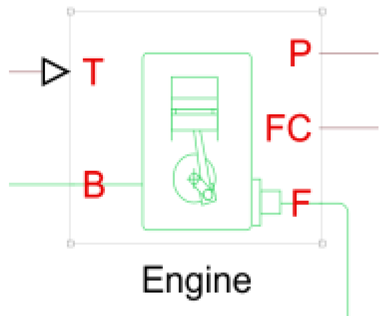


Figure 34 Engine

Connections F and B are mechanical rotational conserving ports associated with the engine crankshaft and engine block, respectively. The crankshaft is an engine component that converts the linear motion of the piston into rotary motion. Connections P and FC are physical signal output ports through which engine power and fuel consumption rate are reported. A scope is connected to the connection P to record the engine power generated. The following are the settings

• Maximum Power: 13.23 HP

• Engine Speed at Maximum Power: 5300 RPM

• Maximum Engine Speed: 6000 RPM

• Inertia: 0.2 kg*m²

• Initial Engine Speed: 1500 RPM

• Stall Speed: 1250 RPM

• Speed Threshold: 100 RPM

The Maximum Power signifies the maximum possible power that can be generated by the engine prior to the transmission of torque across the driveline. The Engine Speed at Maximum Power signifies the rotary speed of the engine crankshaft at the Maximum Power. The simulation fails if the engine speed exceeds the Maximum Engine Speed setting. Since the engine has rotating components, there exists resistance to changes in rotational speeds. As the engine speed varies, an inertia is experienced. The Initial Engine Speed signifies the speed of the engine at the start of the simulation. The Stall Speed signifies that, when the engine speed generated by the model falls below its value, the torque produced is blended to 0 Nm. The Speed Threshold signifies the minimum step change needed in the engine speed, in order to generate torque. Both the Stall Speed and Speed Threshold settings, yield 0 Nm of torque if violated, however, it helps distinguish between possible discrepancies in the simulation.

4. Mechanical Rotational Reference: Represents a mechanical rotational reference point.

Figure 35 Rigid Frame

It is used to connect mechanical rotational ports that are rigidly affixed to the frame. In this case, the mechanical rotational port from the engine connection port B, is rigidly attached to the frame, which is the vehicle body.

5. Inertia: Represents an ideal mechanical rotational inertia. All rotating components have inertia. Some blocks are provided with an option to set the inertia. Additional inertia blocks are used where there is no option.

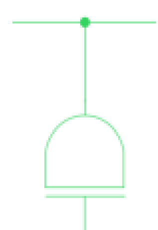


Figure 36 Inertia Module

The block has one mechanical rotational conserving port. The block positive direction is from its port to the reference point. This means that the inertia torque is positive if the inertia is accelerated in the positive direction.

6. Torque Converter: Represents a three-part torque converter consisting of impeller, turbine, and stator. The impeller is mechanically moved by the engine. The turbine drives the load produced. The stator is positioned in between the turbine and the impeller to alter the level of oil flow from then turbine to the impeller. For this purpose, the stator remains in a fixed position. The torque converter is responsible for separating the torque from the power source (engine) and multiplying it to be sent through the driveline by a fluid coupling mechanism. Connections I (impeller) and T (turbine) are mechanical rotational conserving ports associated with the impeller and turbine, respectively. The impeller takes the input from the engine crankshaft.

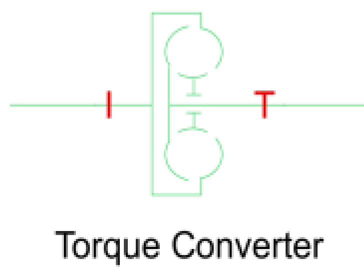


Figure 37 Torque Converter

The following are the settings

- Torque Transmission Time Constant: 0.02 s
- Speed Ratio Vector: [0.0, 0.5, 0.6, 0.7, 0.8, 0.87, 0.92, 0.94, 0.96, 0.97]
- Torque Ratio Vector: [2.232, 1.5462, 1.4058, 1.2746, 1.1528, 1.0732, 1.0192, 0.9983, 0.9983, 0.9983]

The Torque Transmission Time Constant signifies the fixed time period taken to convert the input power to the impeller as output torque from the turbine. For forward movement or acceleration, the torque needs to be positive; it flows from port I (input) to port T (output). The torque ratio is (Output torque)/ (Input torque). The speed ratio is (Output angular speed)/ (Input angular speed). The speed and torque ratio vectors are function block defaults.

7. Gear Box: Represents 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. Connections S and O are mechanical rotational conserving ports associated with the box input and output shaft, respectively. The gear ratio is determined as the ratio of the input shaft angular velocity to that of the output shaft. The input shaft angular velocity is a characteristic of the driving gear, whilst the output shaft angular velocity is a characteristic of the driven gear. Since the gears are of different sizes with different number of teeth, the gear ratio provides a measure of the combined efficiency. The gearbox takes the input from the torque converter turbine.

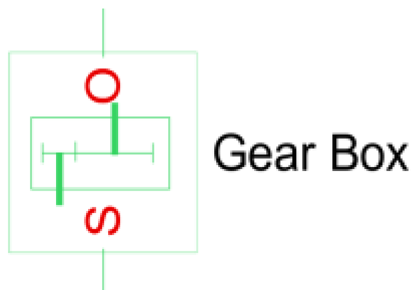


Figure 38 Gear Box

The following is the setting: -

• Gear Ratio: 2

The block generates torque in positive direction if a positive torque is applied to the input shaft and the gear ratio is assigned a positive value.

8. Differential: Represents the differential which is arranged as a planetary bevel gear train equipped with an additional bevel gear transmission between the driveshaft and the carrier. The pinion gear of this transmission is attached to the driveshaft while the large bevel crown gear is affixed to the carrier. The differential allows the outer wheel to rotate faster than the inner wheel in a turn. This is important in turns as the outer wheel rolls farther and faster than the inner wheel. The average of the rotational speeds of the two wheels being driven equals the input rotational speed of the drive shaft. An increase in the speed of one wheel is balanced by a decrease in the speed of the other, by splitting the angular rotational velocities depending on the direction of the turn.

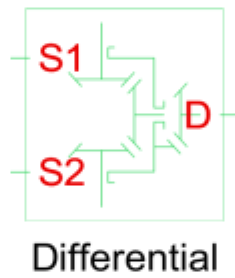


Figure 39 Differential

The following are the settings: -

• Crown wheel location: Right

• Carrier (C) to driveshaft (D) teeth ratio (NC/ND): 4

• Carrier inertia: 0 kg*m²

• Planet gear inertia: 0 kg*m²

Connections D, S1, and S2 are mechanical rotational conserving ports associated with the driveshaft and the two output shafts, respectively. S1 and S2 are the shafts belonging to the two sun gears. When there is no relative slippage across the differential, and if the crown wheel is located to the right of the center line, then S1 and S2 rotate forward, if D rotates forward. The differential takes the input from the gearbox output shaft.

9. Tire: Represents the tire model used in the vehicle.

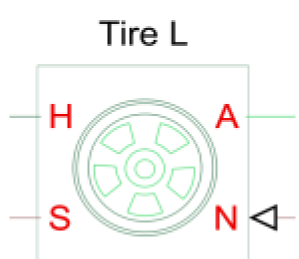


Figure 40 Tire

Connection A is the mechanical rotational conserving port for the wheel axle. Connection H is the mechanical translational conserving port for the wheel hub through which the thrust developed by the tire is applied to the vehicle. Connection N is a physical signal input port that applies the normal force acting on the tire. The force is considered positive if it acts downwards.

Connection S is a physical signal output port that reports the tire slip. The models discussed below use four tires, however only the two driving tires are modelled. The input to the tire at the wheel axle, is provided from the differential shafts.

The following are the settings: -

- Rolling Radius: 0.22505 m
- Rolling Resistance Constant: 0.02

The rolling resistance in tires is caused due to the non-elastic effects that are experienced due to the hysterical losses in the compression and expansion of the tire region which is in contact with the road surface. The rolling radius signifies the radius of the tire with a fixed load. The rolling resistance constant value corresponds to cars on concrete or asphalt roads.

10. Vehicle Body: Represents a two-axle vehicle body in longitudinal motion. The block accounts for body mass, aerodynamic drag, road incline, and weight distribution between axles due to acceleration and road profile. The vehicle does not pitch or move vertically relative to the ground.

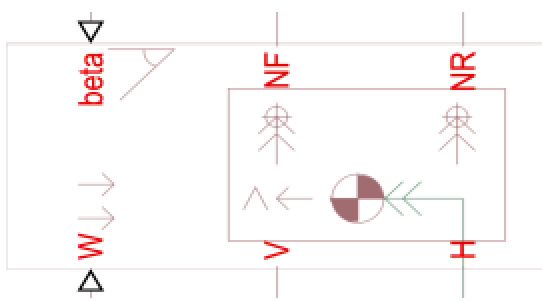


Figure 41 Vehicle Body

Connection H is the mechanical translational conserving port associated with the horizontal motion of the vehicle body. The resulting traction motion developed by tires is connected to this port. Connections V, NF, and NR are physical signal output ports for vehicle velocity and front and rear normal wheel forces, respectively. Since the models used are rear wheel driven, the NF physical signal output port is ignored. Wheel forces are considered positive if acting downwards. Connections W and beta are physical signal input ports corresponding to headwind speed and road inclination angle, respectively. The connections to W and beta are provided from the input control block.

The following are the settings: -

• Mass: 750 kg for conventional and 1000 for hybrid
• Number of wheels per axle: 2
• CG height above ground: 0.4 m
• Frontal area: 2.111948 m^2
• Drag coefficient: 0.31
• Initial velocity: 0 km/hr

The drag coefficient corresponds to vehicles shaped like the Bajaj Quet. Mass represents the sum of kerb-weight and the load present in the vehicle. For simulation purposes, one person (70 kg) is considered to be present in the vehicle. The center of gravity (CG) parameters calculate the effect of weight distribution. The frontal area and the drag coefficient account for the aerodynamic force experienced by the vehicle.

11. Solver: Represents the ordinary differential equation (ODE) solver. The default solver is used, ode23t.

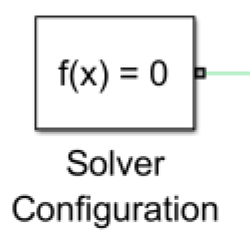


Figure 42 ODE Solver

This block solves for acceleration at every time step in order to compute the speed vs time response graph.

12 DC Motor

This block represents the electrical and torque characteristics of a DC motor. The block assumes that no electromagnetic energy is lost, and hence the back-emf and torque constants have the same numerical value when in SI units. Motor parameters can either be specified directly, or derived from no-load speed and stall torque. If no information is available on armature inductance, this parameter can be set to some small non-zero value.

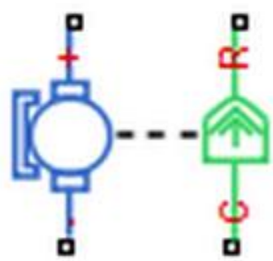


Figure 43 DC motor

When a positive current flow from the electrical + to - ports, a positive torque acts from the mechanical C to R ports. Motor torque direction can be changed by altering the sign of the back-emf or torque constants.

13 DC/DC Convertor

Behavioral model of an ideal DC-DC converter. The block can be used to represent unidirectional or bidirectional converters without the need to simulate individual switching events. The supply side can be connected to any voltage, and the regulated-side voltage has optional droop.

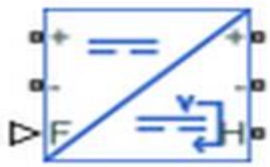


Figure 44 DC-DC converter

Note that the two electrical networks connected to the supply-side and regulated-side terminals must each have their own Electrical Reference block.

14 Planetary gear

Represents a planetary gear train of two degrees of freedom consisting of carrier, ring, planet, and sun gears. The block is built as a structural model using Sun-Planet and Ring-Planet planetary subcomponent blocks. No inertia or compliance is modeled in this block. You can optionally include gear meshing and viscous bearing losses. Meshing losses are parameterized in terms of the ordinary efficiencies of the sun-planet and ring-planet engagements. The ordinary efficiency is the efficiency with the carrier fixed.

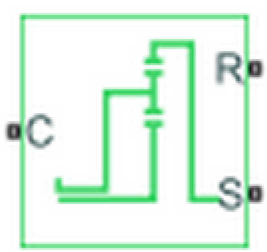


Figure 45 planetary gear

Connections C, R, and S are mechanical rotational conserving ports associated with the carrier, ring, and sun shafts, respectively. Optionally include thermal effects and expose thermal conserving port H by right-clicking on the block and selecting Simscape block choices to switch between variants.

15 Battery

This block models a battery. If you select Infinite for the Battery charge capacity parameter, the block models the battery as a series internal resistance and a constant voltage source. If you select Finite for the Battery charge capacity parameter, the block models the battery as a series internal resistance plus a charge-dependent voltage source defined by:

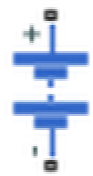


Figure 46 battery

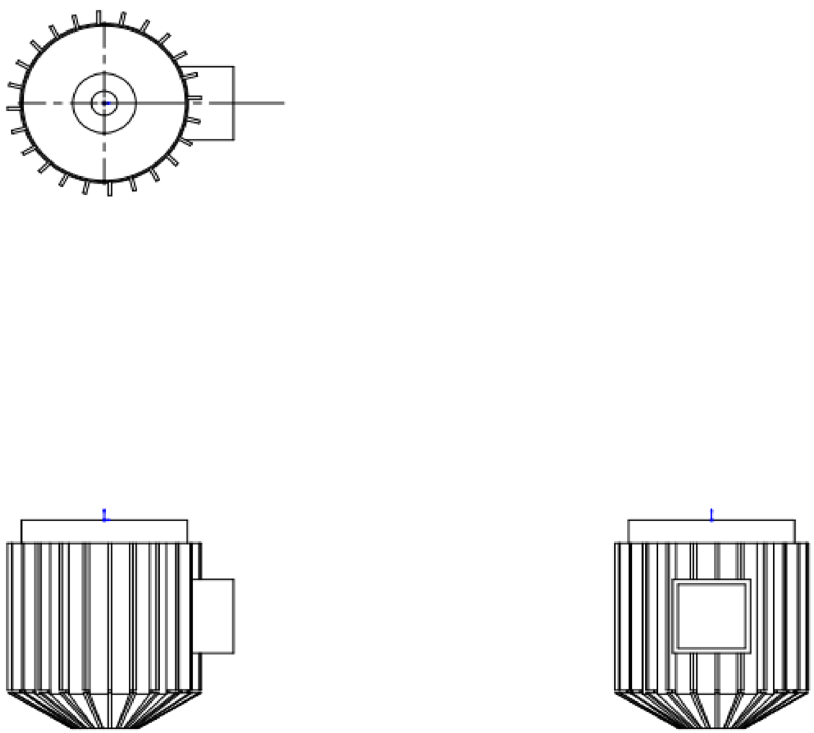
16 Electrical ground

The electrical reference block represents an electrical ground. Electrical conserving ports of all the blocks that are directly connected to ground must be connected to an electrical reference blick. A model with electrical elements must contain at least one electrical reference block.

Figure 47 Electrical ground

APPENDIX B

The figures shown below are Solid Work models of some components used in hybrid Bajaj Quet.



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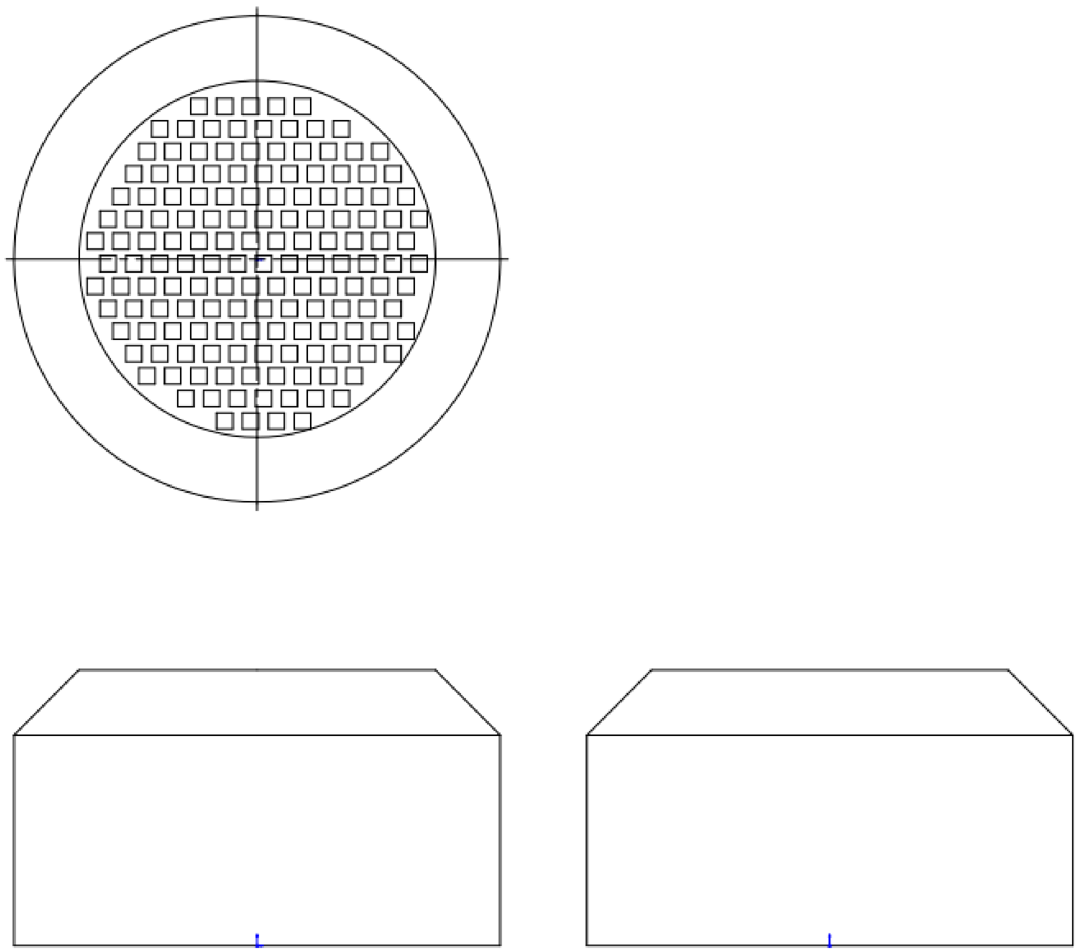
Date: Sept 10, 2019	Front Cover	



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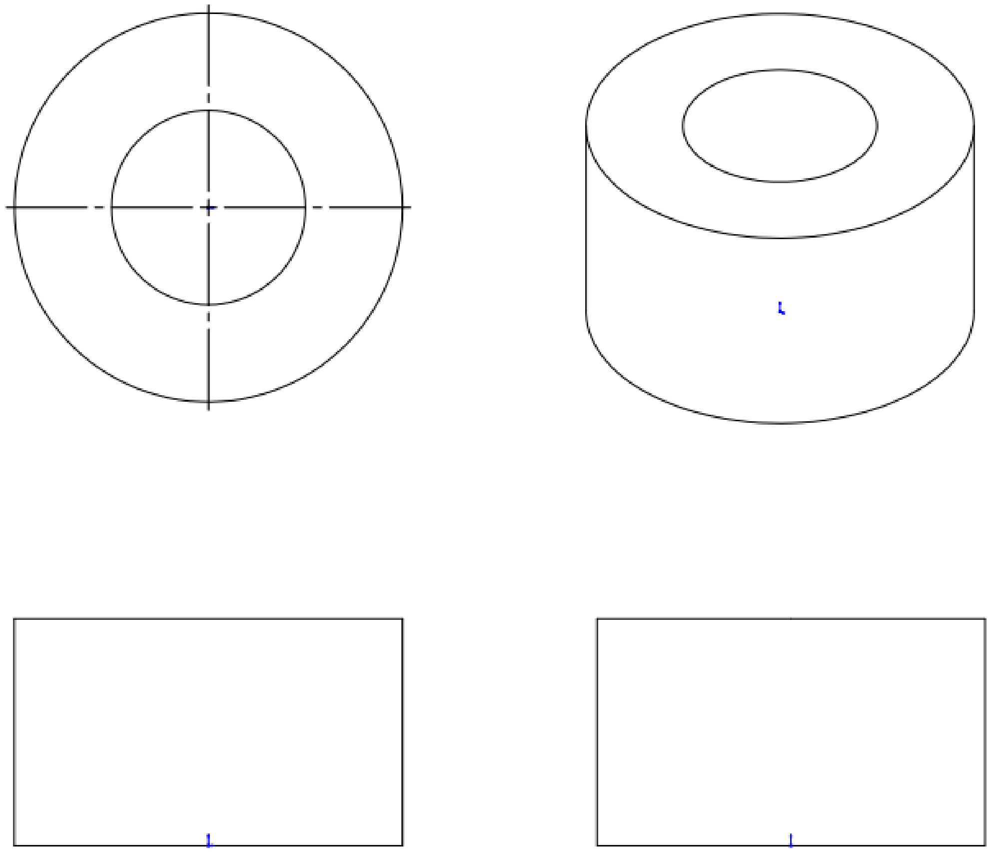

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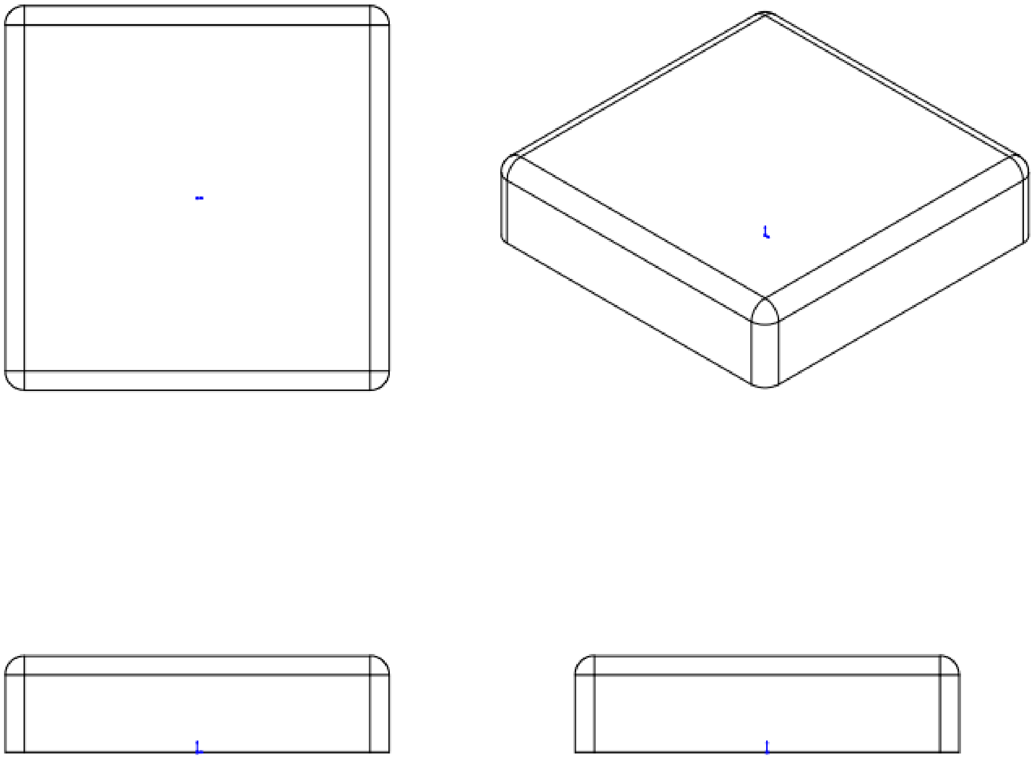

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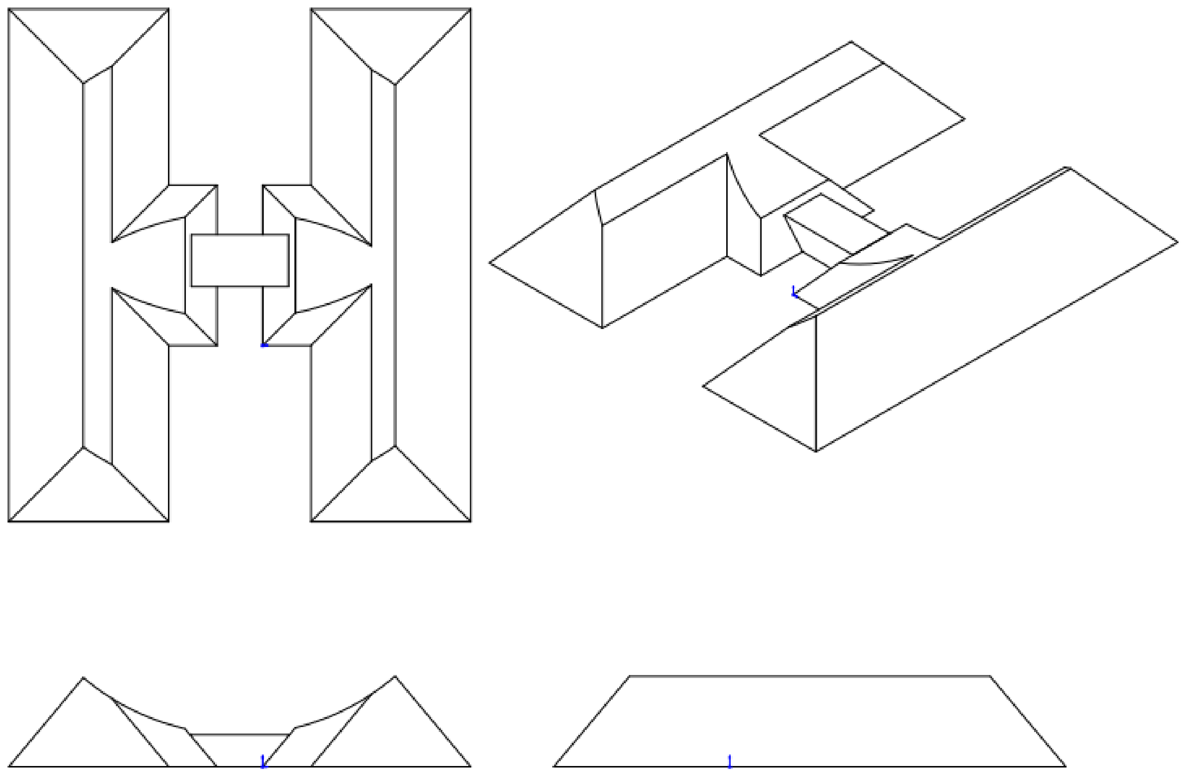

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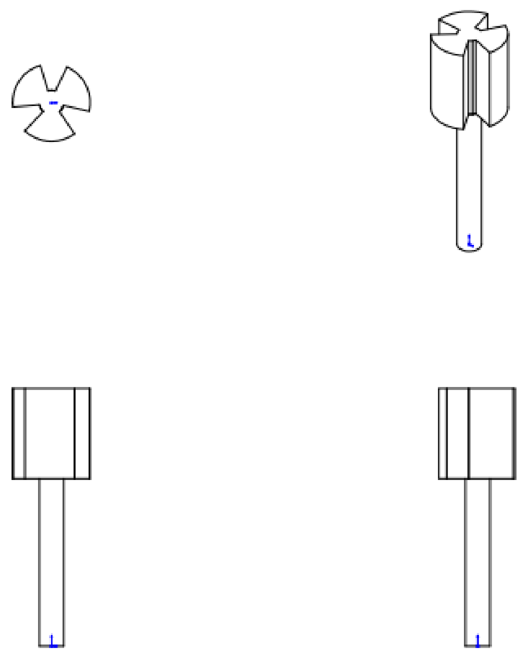

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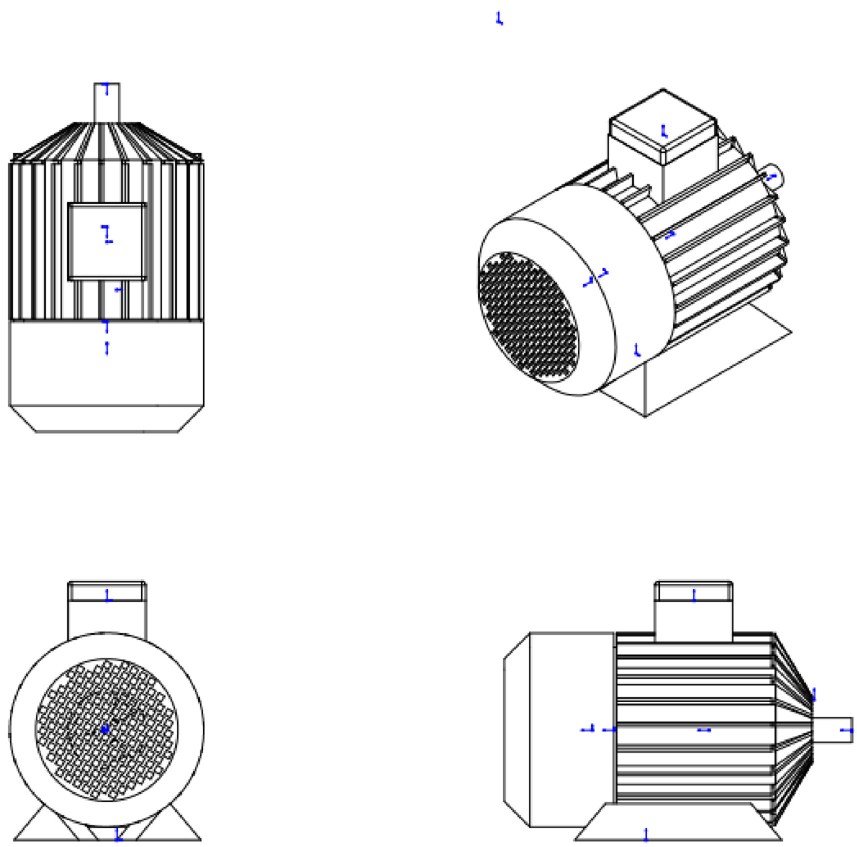
Advisor: Ramesh Babu		Dr. No: 06
Date: Sept 10, 2019	Rotor	



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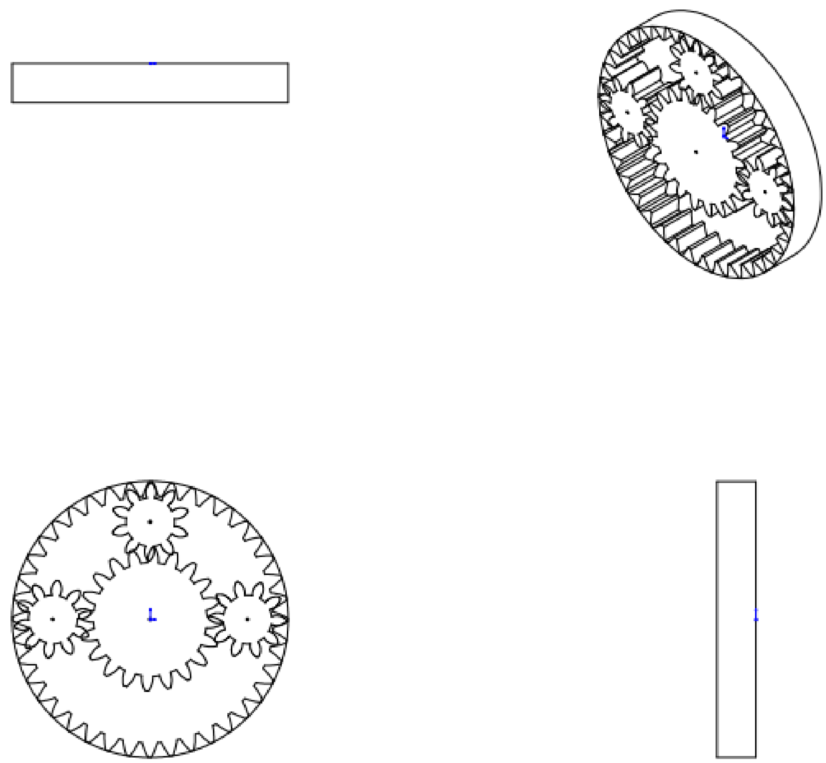
Advisor: Ramesh Babu		Dr No 07
Date: Sept 10, 2019	Motor Assembly	



Dr By: Surafel Kebede	Adama Science and Technology University Automotive Engineering	Scale 1:2
Advisor: Ramesh Babu		Dr no 08
Date: Sept 10, 2019	Planetary Gear set	