Palestine PolytechnicUniversity

College of Engineering and Technology
Mechanical Engineering Department

Graduation Project

Parallel Hybrid Electric Vehicle(PHEV) Design and Building

Project Team

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Hebron-Palestine

June , 2010

PalestinePolytechnicUniversity
(PPU)
Hebron-Palestine

PROJECT NAME

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According to the project supervisor and according to the agreement of the testing committee members, this project is submitted to the Department of Mechanical Engineering at college of engineering and technology in partial fulfillment of the requirements of (B.SC) degree.

Supervisor Signature

Qawasmi M.
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Examine communitySignature

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Department Head Signature

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June, 2010

Abstract

This project comes as a response to the modern trends in the automotive world ,which could be summarized into two main factors: the growing interests in the protection of the environment and, the reduction of pollutants, the trend towards reducing dependence on traditional fuels which become a key element in the scientific automotive research, and here comes the idea of a hybrid vehicle running on an additional source of energy in addition to the conventional fuelssuch as electricity and hydraulic pressure.

A parallel hybrid which includes more than one energy source can provide propulsion power; the heat engine (internal combustion engine) and the electric motor .

The project was implemented on four-wheel drive (4WD) vehicle with diesel engine, electric machines will be incorporated to drive rear axle, here the electric system drives the rear wheels, and the IC engine the front. The vehicle can be traveled by IC engine in front axle in specified operation condition in this mode the electric motor working as generator, and on the other hand can be traveled by electric motor by using rear axle at low speed at city drive cycleand charging the batteries at regenerative braking.

This Hybrid vehicle contains DC\AC inverter and AC driver to control the current and speed of the electric motor, special batteries used for charging, control circuit to control the system in different operation mode. The project shows the design and analysis of the forces affecting on the mechanical system and all electrical circuits calculations.

Abstract (Arabic)

هذا المشروع يأتي استجابة إلى الاتجاهات الحديثة في عالم السيارات , والتي يمكن تلخيصها في عاملين رئيسين هما: الاهتمام المتزايد في حماية البيئة والحد من الملوثات في الغلاف الجوي, إضافة إلى الارتفاع المستمر في الأسعار العالمية للوقود , ولذلك فان الاتجاه نحو تقليل الاعتماد على الوقود التقليدي أصبح عنصرا أساسيا في البحث العلمي المختص بعالم السيارات , ومن هنا ظهرت فكرة السيارة الهجينة التي تعمل على مصدر إضافي للطاقة غير الوقود التقليدي مثل الكهرباء , الممانعة الميكانيكية , والضغط الهيدروليكي.

حيث يتناول هذا المشروع فكرة السيارة الهجينة التي تعمل بمحرك احتراق داخلي ومحرك كهربائي موصولين بشكل متوازي , بحيث ان المحرك الكهربائي موصول بالمحور الخلفي ومحرك الاحتراق الداخلي (الديزل) موصول بالمحور الامامي.

وتستخدم السيارة الهجينة إضافة إلى محرك الاحتراق الداخلي محرك كهربائي يعمل كناقل للحركة وكشاحن للبطاريات , كما تحتوي السيارة على منظم ومتحكم للتيار الكهربائي ,بطاريات خاصة للشحن ,دائرة تحكم بعمل النظام , كما يوضح المشروع التصميمي الهندسي للمشروع من تحليل قوى , وحسابات ميكانيكية وكهربائية , إلى جانب التحكم في آلية عمل النظام في ظروف التشغيل المختلفة .

Scope

The project takes in details a comprehensive illustration of Hybrid Electric Vehicles (HEV) technology based on various previous configuration HEV design.

Mainly it covers a specific HEV type which is parallel hybrid configuration . The idea will be covered in seven chapters as following. Chapter one discusses the problem of pollution and its various forms and illustrates an introduction about HVs considering its importance and gives us a comparison between hybrid and conventional vehicles . Chapter two briefly describes the hybrid vehicle types . Chapter three reviews the types of parallel hybrid and view the advantages and disadvantages of each type of them, and shows an illustrations of the coupling device . Chapter four describes the power sources in PHEV, which are internal combustion engine and electric motor , and describes its electric components . Chapter five focuses on the design methodology of parallel drive trains.Chapter six presents the control strategies for PHEV. Chapter seven focuses on the project design ,acceleration ,velocity ,tractive effort to electric part and IC engine part, control and programming operation mode ,and project building step by step .

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Nomenclature

NOx	Nitrogen Oxides
Co	Carbon Monoxide
Hc	Hydro Carbons
EGR	Engine Gas Recirculation
Co_2	Carbon Dioxide
HEV	Hybrid Electrical Vehicle
M/G	Motor/Generator
EV	Electrical
ICE	Internal Combustion Engine
RBS	Regenerative Braking System
TDC	Top Dead Center
Mep	The Mean Effective Pressure
C	Battier Capacity
PPS	Peaking Power Source
SOC	State-of-Charge
Frr	Rolling Resistance
Fad	Aerodynamic Drag
Fte	Tractive Effort
Fx	Tractive Force
Fcr	Climbing Resistance
TPS	Trettel Position Sensor
PIC	Programmable Interface Controller.
D	Diode
EM	Electrical Motor

Time Table

First Semester

Objective	Week #															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Selecting project title	■	■	■	■												
Establishing Goals					■	■	■									
Data collaction					■	■	■	■	■	■	■	■	■	■		
Touer in the Markiet											■	■	■	■		
Review Mechanecal and Electrical Part							■	■	■	■	■	■	■			
Determining the budget											■	■	■	■		
Design plan											■	■	■	■	■	
Writing Report									■	■	■	■	■	■	■	
Presentation																■

Second Semester

Process	Week #															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Choose the vehicle	■	■	■													
Calculations and selection the suitable EM & other parts				■	■	■	■									
Test the elctrical parts and buying the deficiencies necssary				■	■	■	■	■	■	■	■	■				
Project writing								■	■	■	■	■	■	■	■	
Assembly and programmig the controller								■	■	■	■	■	■	■		
Preparing final draft of the project													■	■	■	
The poject final Presentation																■

Budget Table

NO	Financial statements	Cost in JD
1	Stationery and printing	100
2	Equipment	50
3	Inverter	700
4	Electric motor	300
5	Batteries	350
6	Lathe	300
7	Transportation	50
8	car	500
9	Mechanical connection and gears	300
	Total cost	2650

Chapter One

General Introduction

1.1 Introduction .

1.2 Pollution Problems

1.2.1 Air Pollution

1.2.2 Global Warming

1.3 Petroleum Resources and Costs Problems

1.4 Hybrid Definition .

1.5 History of Hybrid Electric Vehicle .

1.6 Project Objectives.

1.7 Comparison between hybrid vehicle and conventional vehicle.

1.1 Introduction

Today, automobile transportation is in a crisis with regard to the high price of fuel. In the near future, the crisis will take on unprecedented proportions. Not just apparent.

The supply of oil vehicles will diminish and hybrid vehicles will play a major role in diffusing the situation, on the other hand , a problem and big challenge is vehicle emissions and environmental health ,from as early as 1930, the subject of vehicle engine emissions influencing environmental health was very topical for example in the State of California. Already with a population of 2 million vehicles, records of people have died and thousands have become sick due to air pollution related illnesses.

In 1945, after the conclusion of the war, Los Angeles began its air pollution control program and established the Bureau of Smoke Control program. On June 10,1947 the California Governor, Early Warren, signed the Air Pollution Control Act. In 1952 Dr. Aric Haagen-Smit determined the root cause of the smog production. Carbon Monoxide (CO), Hydro Carbons (HC) and various Oxides of Nitrogen or (NOx) combine to generate the smog, which consists of Ozone and Carbon Dioxide.[4]

Carbon Dioxide contributes to global warming and climate change. Ozone, occupying a region of the lower atmosphere, is known to cause respiratory ill health, lung disease and is also thought to make a much greater contribution of the green house effect than even Carbon Dioxide.[4]

It is worth mentioning that the world often tries to solve the problem of pollution resulting from vehicle exhausts, for many years and many different techniques, for example using Exhaust Gas Recirculation (EGR), and Catalytic Converter, and many other system .

This research has been considered as a solution to solve the above mentioned problems, using modern technology, where a hybrid car will be designed to save fuel and reduce vehicle exhaust emission and noise pollution.

However, the large number of automobiles in use around the world has caused serious problems for the environment and human life. Air pollution, global warming, and the rapid depletion of the Earth's petroleum resources are now problems of paramount concern. In recent decades, the research and development activities related to transportation have emphasized the development of high efficiency, clean, and safe transportation. Electric vehicles, hybrid electric vehicles, and fuel cell vehicles have been typically proposed to replace conventional vehicles in the near future. This chapter reviews the problems of air pollution, gas emissions causing global warming, and petroleum resource depletion. It also gives a brief review of the development of electric vehicles, hybrid electric vehicles, and fuel cell technology.

1.2 Pollution Problems

1.2.1 Air Pollutions

At present, all vehicles rely on the combustion of hydrocarbon fuels to derive the energy necessary for their propulsion. Combustion is a reaction between the fuel and the air that releases heat and combustion products. The heat is converted to mechanical power by an engine and the combustion products are released into the atmosphere. A hydrocarbon is a chemical compound with molecules made up of carbon and hydrogen atoms. Ideally, the combustion of a hydrocarbon yields only to carbon dioxide and water, which do not harm the environment. Indeed, green plants "digest" carbon dioxide by photosynthesis. Carbon dioxide is a necessary ingredient in vegetal life. Animals do not suffer from breathing carbon dioxide unless its concentration in air is such that oxygen is almost absent. Actually, the combustion of hydrocarbon fuel in combustion engines is never ideal. Besides carbon dioxide and water, the combustion products contain a certain amount of nitrogen oxides (NOx), carbon monoxides (CO), and unburned hydrocarbons (HC), all of which are toxic to human health.

1.2.2 Global Warming

Global warming is a result of the "greenhouse effect" induced by the presence of carbon dioxide and other gases, such as methane, in the atmosphere. These gases trap the Sun's infrared radiation reflected by the ground, thus retaining the energy in the atmosphere and increasing the temperature. An increased Earth temperature results in major ecological damages to its ecosystems and in many natural disasters that affect human populations. Among the ecological damages induced by global warming, the disappearance of some endangered species is a concern because it destabilizes the natural resources that feed some populations.

Carbon dioxide is the result of the combustion of hydrocarbons . Transportation accounts for a large share (32% from 1980 to 1999) of carbon dioxide emissions. The distribution of carbon dioxide emissions is shown in figure 1.1.

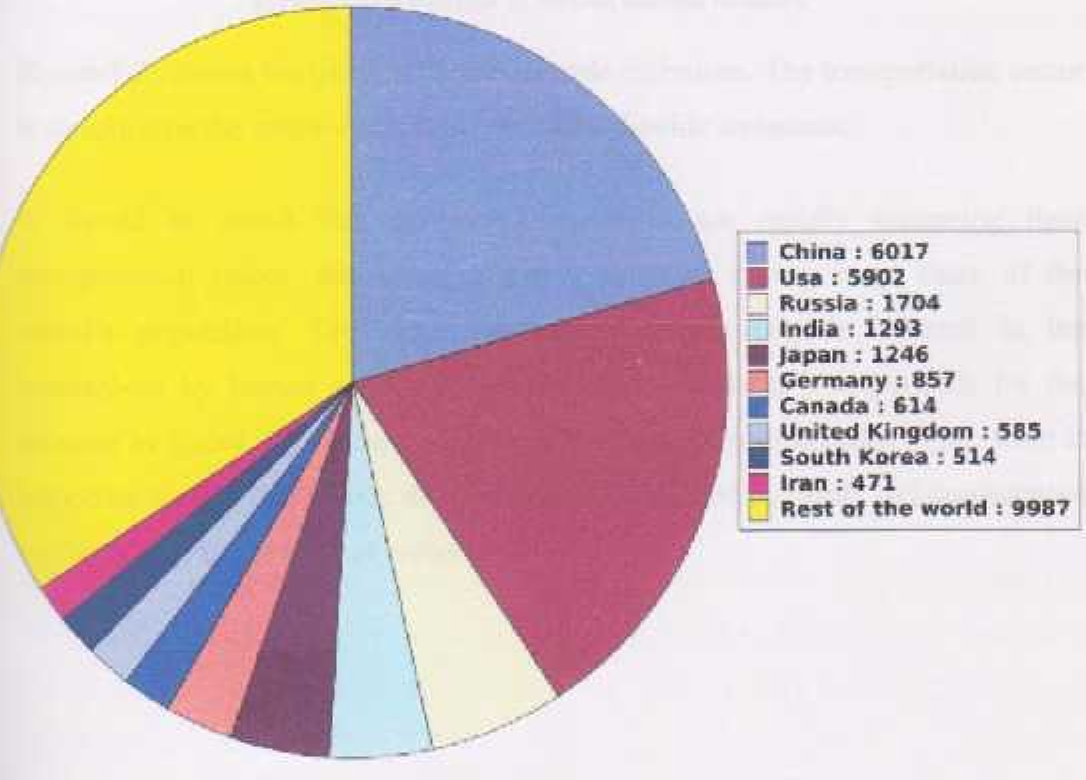


Figure 1.1 : World CO_2 emission by country 2006 [24]

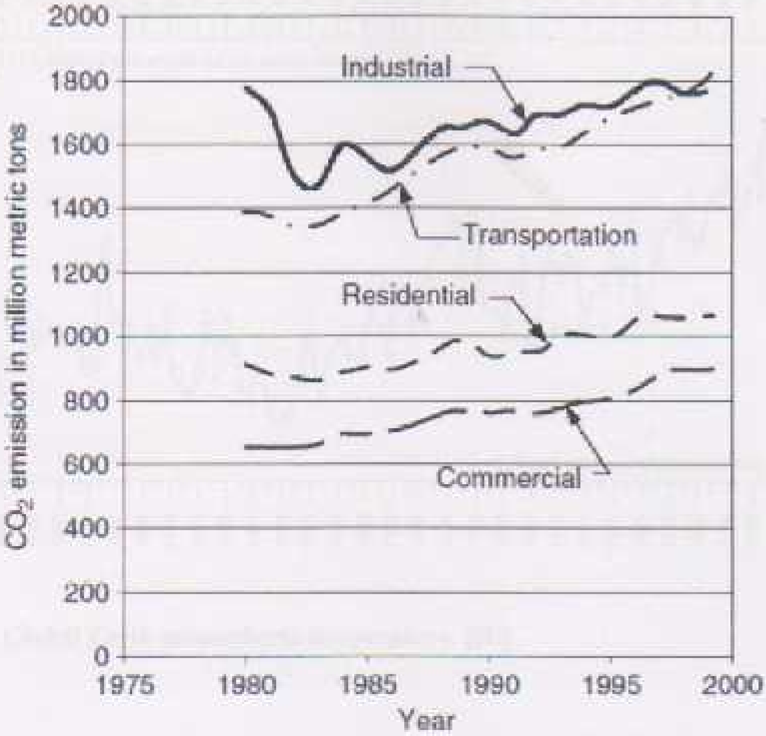


Figure 1.2: Evolution of carbon dioxide emission

Figure 1.2 , shows the trend in carbon dioxide emissions. The transportation sector is clearly now the major contributor of carbon dioxide emissions.

It should be noted that developing countries are rapidly increasing their transportation sector, and these countries represent a very large share of the world's population. The large amounts of carbon dioxide released in the atmosphere by human activities are believed to be largely responsible for the increase in global earth temperature observed during recent decades figure 1.3.It is important to note that carbon dioxide is indeed digested by plants and sequestrated by the oceans in the form of carbonates.

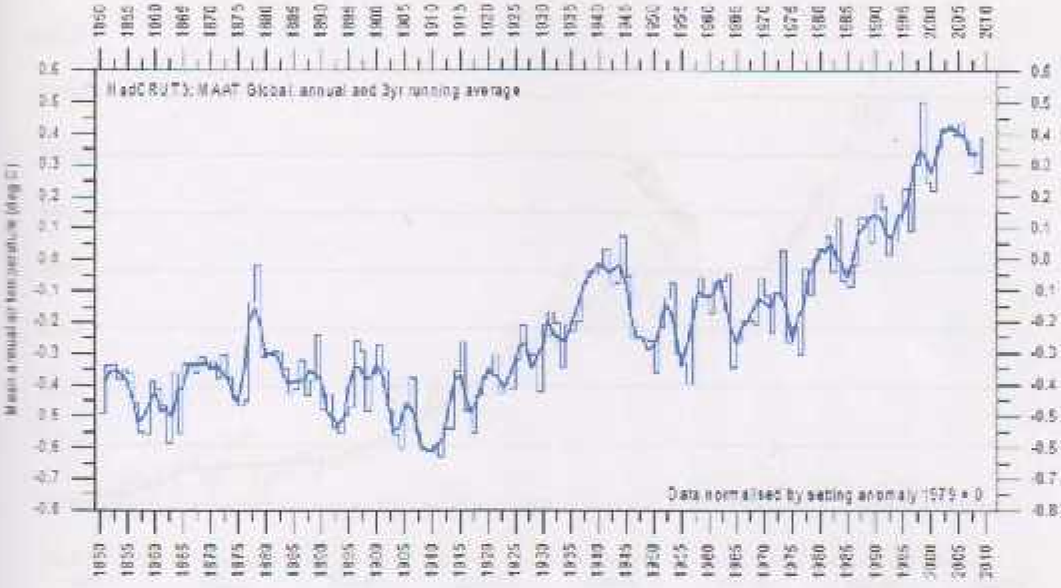


Figure 1.3 : Global Earth atmospheric temperature. [20]

However, these natural assimilation processes are limited and cannot assimilate all of the emitted carbon dioxide, resulting in an accumulation of carbon dioxide in the atmosphere.

1.3 Petroleum Resources and Costs Problems

The growing need for oil in the world. especially to fuel vehicles because of the increased number of cars (in 2030, will be 1.2 billion cars), and political problems and wars, especially the Gulf War and the Iraq war, and also the lack of global oil reserves, and the possibility of depletion of oil fields during the next 100 years, led to increased cost of world oil prices and fuel for vehicles as shown in figure 1.4, which led to a search for other sources, like a renewable energy including hybrid cars.

This research propose a solution which may help in partially solving the problems mentioned above, using modern technology, based on utilizing a hybrid car, which designed to save fuel and reduce vehicle exhaust emission and noise pollution.

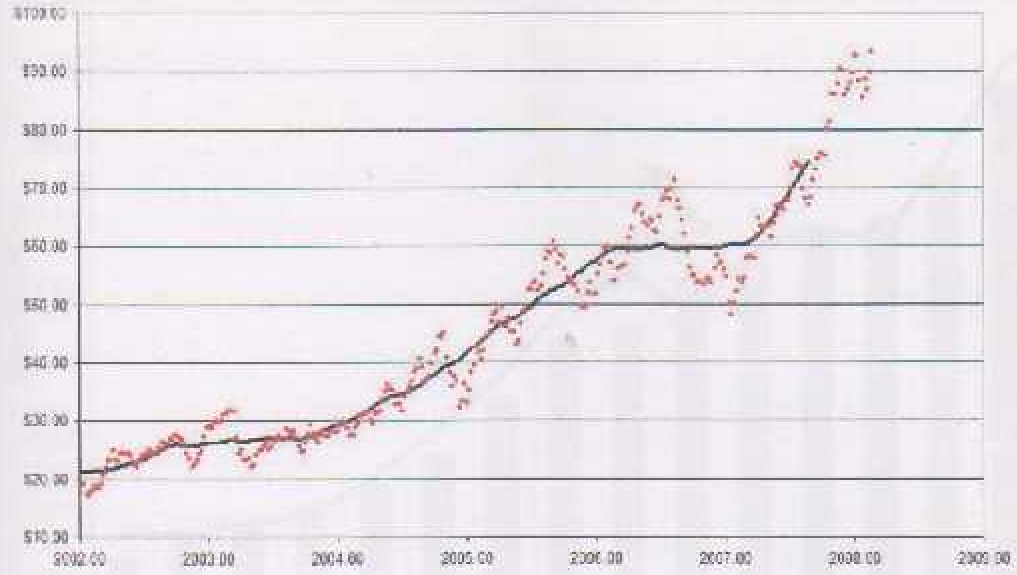


Figure 1.4: World oil price [22]

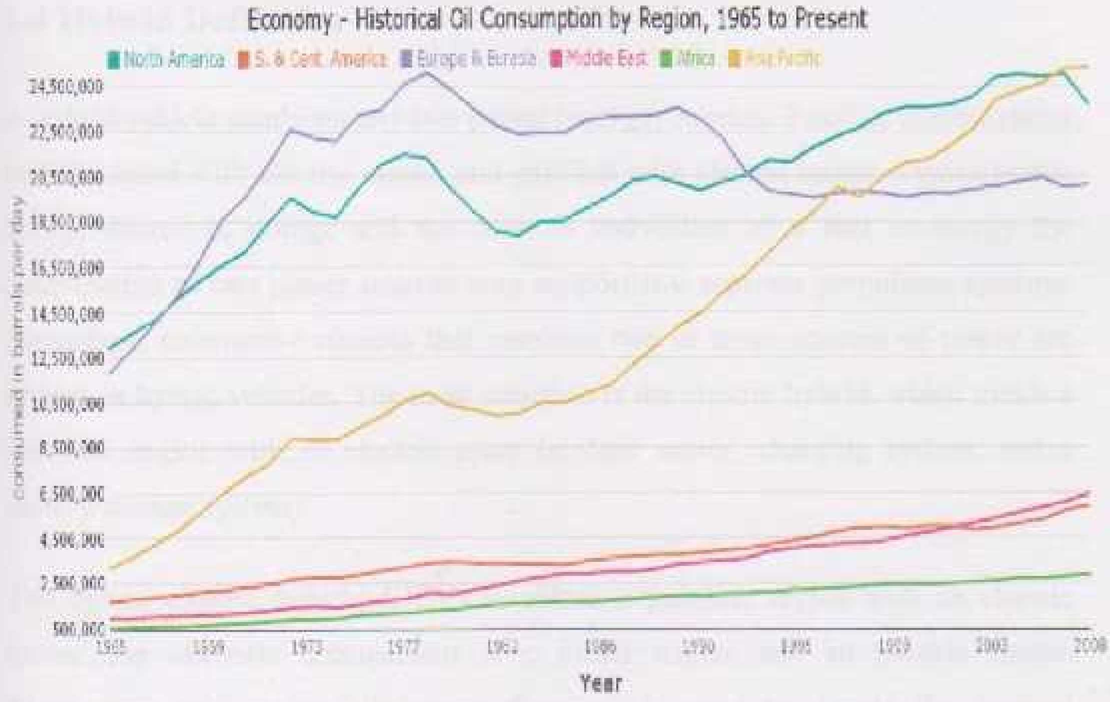


Figure 1.5: Oil consumption per region [21]

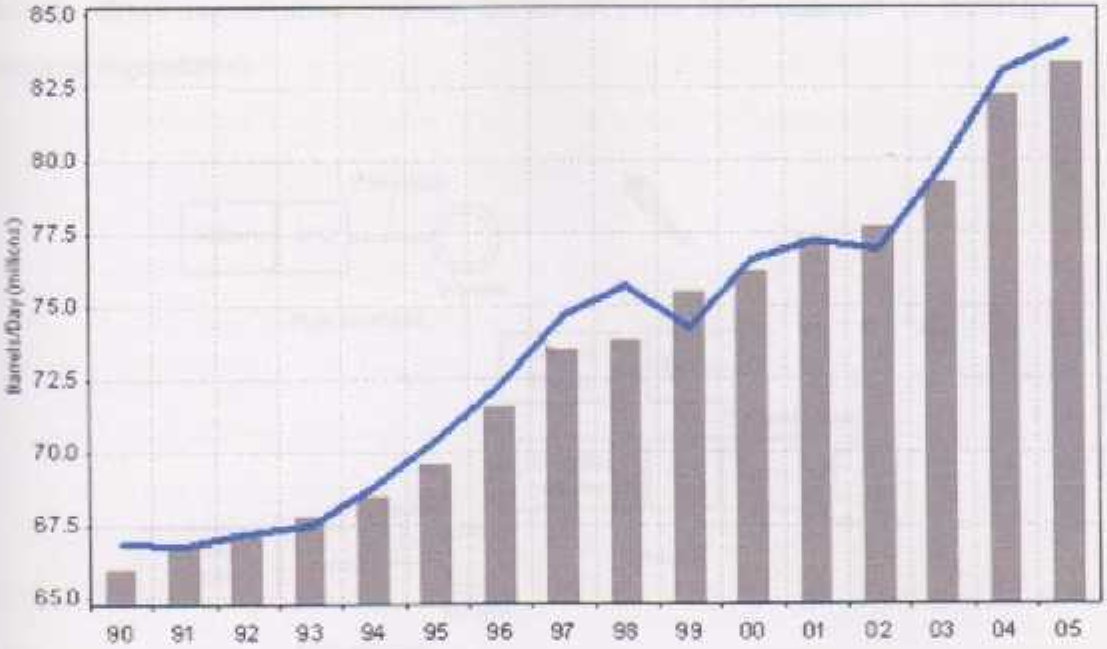


Figure 1.6: World oil consumption [23]

1.4 Hybrid Definition

A hybrid vehicle combines any two power (energy) sources. Possible combinations include diesel with electric motor, and gasoline with electric motor. Typically one energy source is storage and the other is conversion of a fuel to energy the combination of two power sources may support two separate propulsion systems. Nowadays, automotive choices that combine two or more sources of power are known as hybrid vehicles. The most common is the electric hybrid, which melds a gasoline engine with an electric setup (electric motor, charging system, and a battery/storage system).

The hybrid electric vehicle (HEV) combines a gasoline engine with an electric motor. An alternate arrangement is a diesel engine and an electric motor. Throughout this project, the word "engine" is used to denote the internal combustion engine. Further the word "motor" signifies an electric motor or the motor/generator (M/G). As shown in figure 1.7, a hybrid vehicle may consist of a gasoline engine combined with a M/G. An HEV is formed by merging components from a pure electrical vehicle and a pure gasoline vehicle. The EV has an M/G which allows regenerative braking for an EV; the M/G installed in the HEV enables regenerative

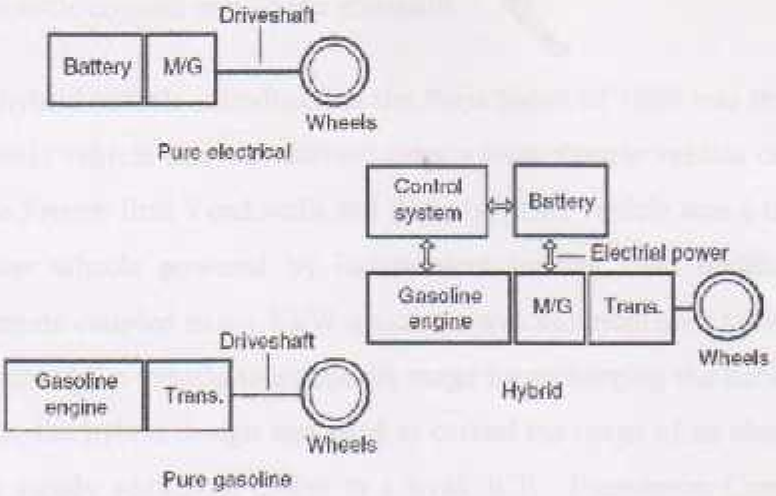


Figure 1.7: Components of a hybrid car. The hybrid is formed by combining a gasoline CV with a pure EV.

braking. For HEV, the M/G is tucked directly behind the engine. In Honda hybrids, the M/G is connected directly to the engine. The transmission appears next in line. This arrangement has two torque producers; the M/G in motor mode, M-mode, and the gasoline engine. The battery and M/G are connected electrically. [1]

1.5 History of Hybrid Electric Vehicles

Surprisingly, the concept of hybrid electric vehicles is almost as old as the automobile itself. The primary purpose, however, was not so much to lower the fuel consumption but rather to assist the ICE to provide an acceptable level of performance. Indeed, in the early days, ICE engineering was less advanced than electric motor engineering.

The first hybrid vehicles reported were shown at the Paris Salon of 1899. These were built by the Pieper establishments of Liege, Belgium and by the Vendovelli and Priestly Electric Carriage Company, France. The Pieper vehicle was a parallel hybrid with a small air-cooled gasoline engine assisted by an electric motor and lead-acid batteries. It is reported that the batteries were charged by the engine when the vehicle coasted or was at a standstill.

The other hybrid vehicle introduced at the Paris Salon of 1899 was the first series hybrid electric vehicle and was derived from a pure electric vehicle commercially built by the French firm Vendovelli and Priestly. This vehicle was a tricycle, with the two rear wheels powered by independent motors. An additional 3/4 hp gasoline engine coupled to a 1.1 kW generator was mounted on a trailer and could be towed behind the vehicle to extend its range by recharging the batteries. In the French case, the hybrid design was used to extend the range of an electric vehicle, and not to supply additional power to a weak ICE. Frenchman Camille Jenatzy presented a parallel hybrid vehicle at the Paris Salon of 1903.

Dr. Victor Wouk is recognized as the modern investigator of the hybrid electric vehicle movement. In 1975, along with his colleagues, he built a parallel hybrid version of a Buick Skylark.1 The engine was a Mazda rotary engine, coupled to a manual transmission. It was assisted by a 15 hp separately excited DC machine, located in front of the transmission.

Despite the two oil crises of 1973 and 1977, and despite growing environmental concerns, no hybrid electric vehicle made it to the market. The researchers' focus was drawn by the electric vehicle, of which many prototypes were built during the 1980s. the lack of interest in hybrid electric vehicles, during this period may be attributed to the lack of practical power electronics, modern electric motors, and battery technologies. The 1980s witnessed a reduction in conventional ICE-powered vehicle sizes, the introduction of catalytic converters, and the generalization of fuel injection.

The most significant effort in the development and commercialization of hybrid electric vehicles was made by Japanese manufacturers. In 1997, Toyota released the Prius sedan in Japan. Honda also released its Insight and Civic Hybrid.

These vehicles are now available throughout the world. They achieve excellent figures of fuel consumption.

Toyota Prius and Honda Insight vehicles have a historical value in that they are the first hybrid vehicles commercialized in the modern era to respond to the problem of personal vehicle fuel consumption.[10]

1.6 Project Objectives

1. Reduce emissions.
2. Reduce fuel consumption .
3. Producing a practical city car .
4. Application of modern technology, as the world mainly car manufacturers started to actually go to this solution as well as for alternative energy in general.
5. Operating each of the internal combustion engine and electric motor at the optimum working conditions.

1.7Comparison between hybrid vehicle and conventional vehicle (1)

	Comparison	hybrid vehicle	conventional vehicle
1	Fuel consumption	Hybrid car consumes less fuel than conventional	More than hybrid by 40%.
2	Cost	Hybrid car more expensive than a conventional car by approximately 25%, but there are tax incentives For hybrid cars	The conventional car, is less expensive than hybrids.
3	Effect to environment	Hybrid cars are environment friendly .	Modern Conventional cars pollute the environment more than hybrid vehicles by 25%.
4	Efficiency	Hybrid cars are designed to work inside the cities, and at slower speeds, so their efficiency is less than conventional cars if it use the electric motor	Conventional cars are more efficient than hybrid cars on the road .. because cars are designed to work on all kinds of ways
5	Maintenance	Because hybrid cars contain electronic parts, electrical, and mechanical connections, they are more complex in most cases. So the cost of maintenance is high	Conventional cars maintenance cost is less than hybrid .

1) This comparison was based on a comparison of the hybrid vehicle model TOYOTA PIRUS 2010, with a conventional vehicle model TOYOTA COROLA 2010. [19]

Hybrid car manufacturers are continually researching for more ways to reduce fuel consumption and better fuel efficiency. Also as more hybrid cars are being adopted, the cost of hybrid cars will reduce making it more affordable for everyone.

Chapter Two

General Hybrid Types

2.1 Introduction

This chapter reviews the types of hybrid vehicles,their designs and differences between various types,it is also reviews classifications of hybrid vehicles, their principle of operation and interaction between various sources of power .

2.2Types by degree of hybridization

2.2.1Full Hybrid

A full hybrid, sometimes also called a strong hybrid, is a vehicle that can run on just the engine, just the batteries, or a combination of both. The Toyota Prius, Ford Escape, and Mercury Mariner Hybrids are examples of this, as these cars can be moved forward on battery power alone. A large, high-capacity battery pack is needed for battery-only operation. These vehicles have a split power path that allows more flexibility in the drivetrain by interconnecting mechanical and electrical power, at some cost in complexity. To balance the forces from each portion, the vehicles use a differential-style linkage between the engine and motor connected to the head end of the transmission.

The Toyota brand name for this technology is Hybrid Synergy Drive, which is being used in the Prius, Highlander sport utility vehicle (SUV), and Camry. A computer oversees operation of the entire system, determining which half should be running, or if both should be in use.[8]

2.2.2 Power Assist Hybrid

Power assist hybrids use the engine for primary power, with a torque-boosting electric motor also connected to a largely conventional powertrain. The electric motor, mounted between the engine and transmission, is essentially a very large starter motor, which operates not only when the engine needs to be turned over, but also when the driver "steps on the gas" and requires extra power. The electric motor may also be used to re-start the combustion engine, deriving the same benefits from shutting down the main engine at idle, while the enhanced battery system is used to power accessories

Honda's hybrids including the Insight use this design, leveraging their reputation for design of small, efficient gasoline engines; their system is dubbed Integrated Motor Assist (IMA). Assist hybrids differ fundamentally from full hybrids in that propulsion cannot be accomplished on electric power alone. However, since the amount of electrical power needed is much smaller, the size of the system is reduced. Starting with the 2006 Civic Hybrid, the IMA system now can propel the vehicle solely on electric power during medium speed cruising.

A variation on this type of hybrid is the Saturn Vue Green LineBAS Hybrid system that uses a smaller electric motor (mounted to the side of the engine), and battery pack than the Honda IMA, but functions similarly.[8]

2.2.3 Mild Hybrid

Mild hybrids are essentially conventional vehicles with oversized starter motors, allowing the engine to be turned off whenever the car is coasting, braking, or stopped, yet restart quickly and cleanly. Accessories can continue to run on electrical power while the engine is off, and as in other hybrid designs, the motor is used for regenerative braking to recapture energy. The larger motor is used to spin up the engine to operating rpm speeds before injecting any fuel.

Many people including the Society of Automotive Engineers do not consider these to be hybrids at all, and these vehicles do not achieve the fuel economy of full hybrid models. A major example is the 2005 Chevrolet Silverado hybrid, a full-size pickup truck. Chevrolet was able to get a 10% improvement on the Silverado's fuel efficiency by shutting down and restarting the engine on demand and using regenerative braking. However no electrical motor was used to provide propulsion rather electrical energy was used to drive accessories like the AC. Mild hybrids often use 42 volt systems to supply the power needed for the startup motor, as well as to compensate for the increasing number of electronic accessories on modern vehicles.

Another way to provide for shutting off a car's engine when it is stopped, then immediately restarting it when it's time to go, is by employing a static start engine. Such an engine requires no starter motor, but employs sensors to determine the exact position of each piston, then precisely timing the injection and ignition of fuel to turn over the engine.[13]

2.2.4 Plug-in Hybrid

A plug-in hybrid electric vehicle (PHEV) has two defining characteristics, firstly it can be plugged in to an electrical outlet to be charged and, secondly has some range that can be traveled on the energy it stored while plugged in. They are full hybrid, able to run in electric-only mode, with larger batteries and the ability to recharge from the electric power grid. And can be parallel or series hybrid designs. They are also called gas-optional, or gradable hybrids. Their main benefit is that they can be gasoline-independent for daily commuting, but also have the extended range of a hybrid for long trips. They can also be multi-fuel, with the electric power supplemented by diesel, biodiesel, or hydrogen. The Electric Power Research Institute's research indicates a lower total cost of ownership for PHEVs due to reduced service costs and gradually improving batteries. The "well-to-wheel" efficiency and emissions of PHEVs compared to gasoline hybrids depends on the energy sources of the grid (the US grid is 50% coal; California's grid is primarily natural gas, hydroelectric power, and wind power). Particular interest in PHEVs is in California where a "million solar homes" initiative is under way, and global warming legislation has been enacted.[14]

2.3Types by Nature of the Power Source

2.3.1 Human Power and Environmental Power Hybrids

Many land and water vehicles use human power combined with a further power source. Common are parallel hybrids, e.g. a boat being rowed and also having a sail set, or motorized bicycles, or a human-electric hybrid vehicle such as the Twike. Also some series hybrids exist, see in hybrid vehicle. Such vehicles can be tribrid vehicles, combining at the same time three power sources e.g. from on-board solar cells, from grid-charged batteries, and from pedals.[8]

2.3.2 Pneumatic Hybrid

Compressed air can also power a hybrid car with a gasoline compressor to provide the power. Motor Development International in France produces such air cars. A team led by Tsu-Chin Tsao, a UCLA mechanical and aerospace engineering professor, is collaborating with engineers from Ford to get Pneumatic hybrid technology up and running. The system is similar to that of a hybrid-electric vehicle in that braking energy is harnessed and stored to assist the engine as needed during acceleration.[8]

2.3.3 Hydraulic Hybrid

A hydraulic hybrid vehicle uses hydraulic and mechanical components instead of electrical ones. A variable displacement pump replaces the motor/generator, and a hydraulic accumulator (which stores energy as highly compressed nitrogen gas) replaces the batteries. The hydraulic accumulator, which is essentially a pressure tank, is potentially cheaper and more durable than batteries. Hydraulic hybrid technology was originally developed by Volvo Flygmotor and was used experimentally in buses from the early 1980s and is still an active area.

Initial concept involved a giant flywheel (see Gyro bus) for storage connected to a hydrostatic transmission, but it was later changed to a simpler system using a hydraulic accumulator connected to a hydraulic pump/motor. It is also being actively developed by Eaton and several other companies, primarily in heavy vehicles like buses, trucks and military vehicles. An example is the Ford F-350 Mighty Tonka concept truck shown in 2002. It features an Eaton system that can accelerate the truck up to highway speeds.

The energy recovery rate is higher and therefore the system is more efficient than battery charged hybrids, demonstrating a 60% to 70% increase in economy in EPA testing. [8]

2.3.4 Fuel Cell Hybrid

Fuel cell vehicles are often fitted with a battery or super capacitor to deliver peak acceleration power and to reduce the size and power constraints on the fuel cell (and thus its cost); this is effectively also a series hybrid configuration.[8]

2.3.5Electric-Internal Combustion Engine Hybrid

There are many ways to create an electric-internal combustion hybrid. The variety of electric-ICE designs can be differentiated by how the electric and combustion portions of the powertrain connect, at what times each portion is in operation, and what percent of the power is provided by each hybrid component. Two major categories are series hybrids and parallel hybrids, though parallel designs are most common today.

Most hybrids, no matter the specific type, use regenerative braking to recover energy when slowing down the vehicle. This simply involves driving a motor so it acts as a generator.

Many designs also shut off the internal combustion engine when it is not needed in order to save energy. That concept is not unique to hybrids; Subaru pioneered this feature in the early 1980s, and the Volkswagen Lupo 3L is one example of a conventional vehicle that shuts off its engine when at a stop. Some provision must be made, however, for accessories such as air conditioning which are normally driven by the engine. Furthermore, the lubrication systems of internal combustion engines are inherently least effective immediately after the engine starts; since it is upon startup that the majority of engine wear occurs, the frequent starting and stopping of such systems reduce the lifespan of the engine considerably. Also, start and stop cycles may reduce the engine's ability to operate at its optimum temperature, thus reducing the engine's efficiency.[8]

2.4 Types by Drivetrain Structure

2.4.1 Series Hybrid Electric Drive Trains

A series hybrid drive train is a drive train where two power sources feed a singlepower plan(electric motor) that propels the vehicle,show figure 2.1. The most commonlyfound series hybrid drive train is the series hybrid electric drive trainunidirectional energy converter is an engine coupled to an electric generator. The output of the electric generator is connected to an electric power busthrough an electronic converter (rectifier). The bidirectional energy source isan electrochemical battery pack, connected to the bus by means of a power

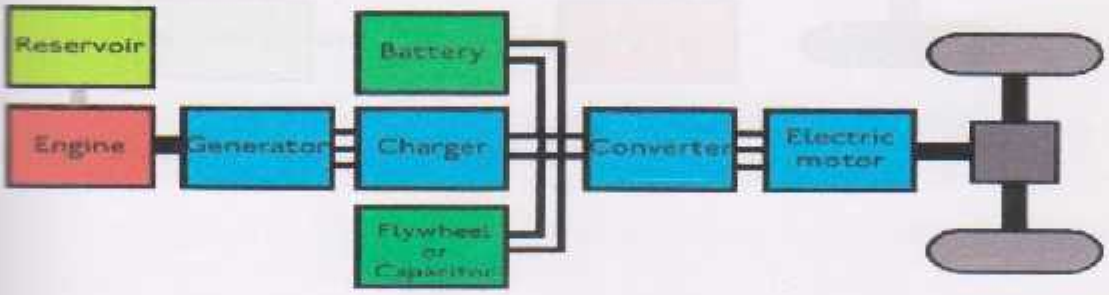


Figure 2.1:Structure of a series hybrid vehicle.

electronics converter (DC/AC converter). The electric power bus is also connectedto the controller of the electric traction motor. The traction motor canbe controlled either as a motor or a generator, and in forward or reversemotion. This drive train may need a battery charger to charge the batteriesby a wall plug-in from the power network.[8]

2.4.2 Parallel Hybrid Electric Drive Trains

Parallel hybrid systems, which are most commonly produced at present, have both an internal combustion engine (ICE) and an electric motor connected to a mechanical transmission ,show figure 2.2. Most designs combine a large electrical generator and a motor into one unit, often located between the combustion engine and the transmission, replacing both the conventional starter motor and the alternator. To store power, a hybrid uses a large battery pack with a higher voltage than the normal automotive 12 volts. Accessories such as power steering and air conditioning are powered by electric motors instead of being attached to the combustion engine. This allows efficiency gains as the accessories can run at a constant speed, regardless of how fast the combustion engine is running.

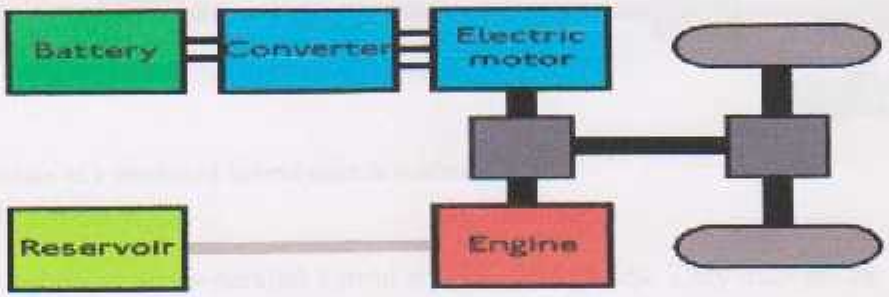


Figure2.2 :Structure of a parallel hybrid electric vehicle

Parallel hybrids can be categorized by the way the two sources of power are mechanically coupled. If they are joined at some axis truly in parallel, the speeds at this axis must be identical and the supplied torques add together. Most electric bicycles are in effect of this type. When only one of the two sources is being used, the other must either also rotate in an idling manner or be connected by a one-way clutch or freewheel. With cars it is more usual to join the two sources through a differential gear. Thus the torques supplied must be the same and the speeds add up, the exact ratio depending on the differential characteristics. When only one of the two sources is being used, the other must still supply a large part of the torque or be fitted with a reverse one-way clutch or automatic clamp.

Parallel hybrids can be further categorized depending upon how balanced the different portions are at providing motive power. In some cases, the combustion engine is the dominant portion (the electric motor turns on only when a boost is needed) and vice versa. Others can run with just the electric system operating.[8]

2.4.3Power-split or series-parallel hybrid

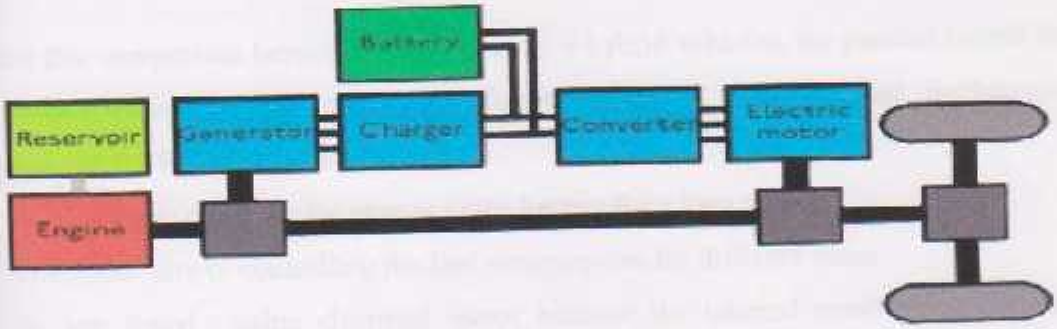


Figure 2.3 : Structure of a combined hybrid electric vehicle

Power-split hybrid or series-parallel hybrid are parallel hybrids. They incorporate power-split devices allowing for power paths from the engine to the wheels that can be either mechanical or electrical, as shown infigure 2.3. The main principle behind this system is the decoupling of the power supplied by the engine (or other primary source) from the power demanded by the driver.

- A combustion engine's torque is minimal at lower RPMs and, in a conventional vehicle, a larger engine is necessary for acceleration from standstill. The larger engine, however, has more power than needed for steady speed cruising. An electric motor, on the other hand, exhibits maximum torque at standstill and is well-suited to complement the engine's torque deficiency at low RPMs. In a power-split hybrid, a smaller, less flexible, and highly efficient engine can be used. The conventional Otto cycle (higher power density, more low-rpm torque, lower fuel efficiency) is often also modified to a Miller cycle or Atkinson cycle (lower power density, less low-rpm torque, higher fuel efficiency). The smaller engine using a more efficient cycle contributes significantly to the higher overall efficiency of the vehicle.

- Interesting variations of the simple design (pictured at right) found, for example, in the well-known Toyota Prius.[15].

2.5 Conclusion

After this comparison between many types of a hybrid vehicles, the parallel hybrid electric vehicle waschosenin this project for further studying, designing and implementation, because of the following reasons :

1. The ability to conserve the energy in the battery for a long time .
2. The possibility of controlling the fuel consumption for different cases :

a) At low speed ; using electrical motor because the internal combustion enginewhich consume larger amount of fuel at low speed in relation to traveled distance and causes high pollution

b) At high speed ; using I.C engine because atspeed (80-90 km/h). I.C engine consumes lower amount of fuel in relation to travelled distance with high performance ,and low pollution .

Unlike the series hybrid drive train, the parallel hybrid drive train hasfeatures that allow both the engine and traction motor to supply theirmechanical power in parallel directly to the driven wheels.

Chapter Three

Parallel HybridElectric

VehiclesDrive Train

3.1 Introduction

A parallel hybrid vehicle is a vehicle in which more than one energy source can provide propulsion power. The heat engine (ICE) and the electric motor are configured in parallel, with a mechanical coupling in some cases that blends the torque coming from the two sources. The components arrangement of a parallel hybrid are shown in figure 3.1

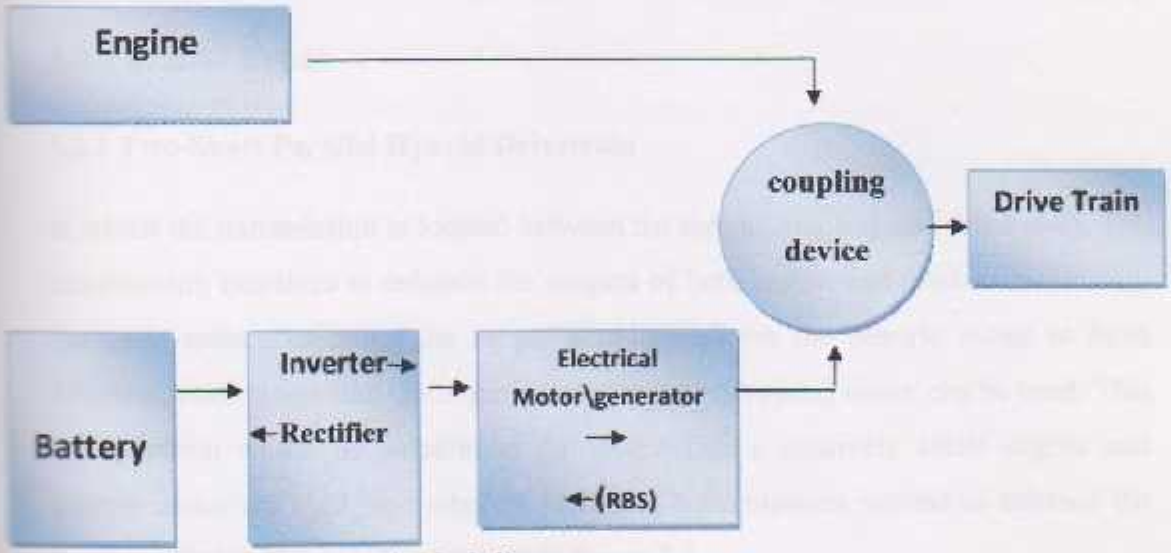


Figure3.1:Parallel HEV drive train block diagram

3.1.1 Advantages of a Parallel HEV

1. It needs two propulsion components: ICE and motor/generator. In parallel HEV, the motor can be used as the generator and vice versa.

2. A smaller engine and a smaller motor can be used to get the same performance, until batteries are depleted. For short-trip missions, both can be rated at half the maximum power to provide the total power, assuming that the batteries are never depleted. For long-distance trips, the engine may berated for the maximum power, while the motor/generator may still be rated to half the maximum power or even smaller.

3. High performance in high way .

3.1.2 Disadvantages of a Parallel HEV

1. The control complexity increases significantly, because power flow has to be regulated and blended from two parallel sources.

2. The power blending from the ICE and the motor necessitates a complex mechanical device.

3.2 Parallel Types

3.2.1 Two-Shaft Parallel Hybrid Drivetrain

In which the transmission is located between the torque coupling and drive shaft. The transmission functions to enhance the torques of both engine and electric motor with the same scale. Designing the torque coupling allows the electric motor to have different speed range than the engine; therefore, a high-speed motor can be used. This configuration would be suitable in the case when a relatively small engine and electric motor are used, and where a multigear transmissions needed to enhance the tractive effort at low speeds as shown in figure 3.2.

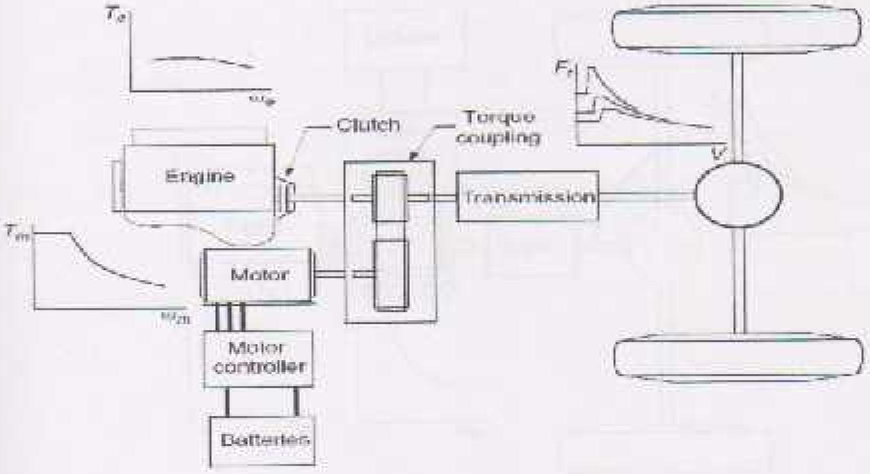


Figure 3.2: Two-shaft parallel hybrid drive train

3.2.2 Single-Shaft Torque Combination Parallel Hybrid Electric Drivetrain

The simple and compact architecture of the torque coupling parallel hybrid is the single-shaft configuration where the rotor of the electric motor functions as the torque coupling as shown in figure 3.3 and figure 3.4. A transmission may be either placed behind an electric motor that is connected to the engine through a clutch or between the engine and the electric motor. The former configuration is referred to as "pretransmission" (the motor is ahead of the transmission, figure 3.3) and the latter is referred to as "posttransmission" (the motor is behind the transmission, figure 3.4). In the pretransmission configuration, both the engine torque and motor torque are modified by the transmission. The engine and motor must have the same speed range. This configuration is usually used in the case of a small motor, referred to as a mild hybrid drive train, in which the electric motor functions as an engine starter, electrical generator, engine power assistant, and regenerative braking. However, in the posttransmission configuration as shown in figure 3.5, the transmission can only modify the engine torque while the motor torque is directly delivered to the driven wheels. This configuration may be used in the drive train where a large electric motor with a long constant power region is used.

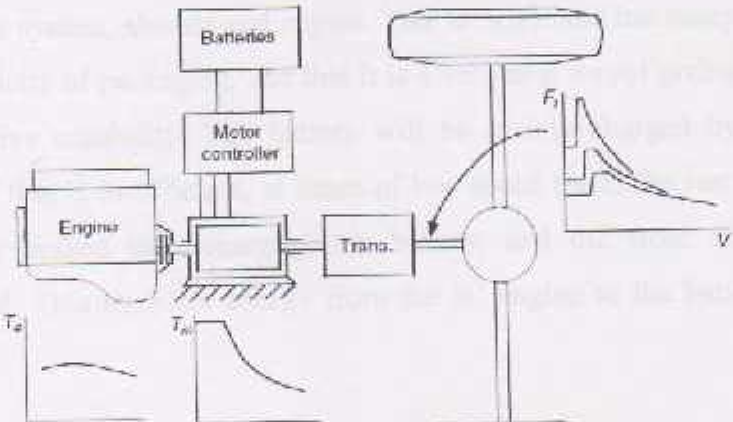


Figure3.3:Pretransmission single-shaft torque combination parallel hybrid electric drivetrain

The transmission is only used to change the engine operatingpoints to improve the vehicle performance and engine operating efficiency. It should be noted that the batteries cannot be charged from the engine by running the electric motor as a generator when the vehicle is at a standstill and the motor is rigidly connected to the driven wheels.

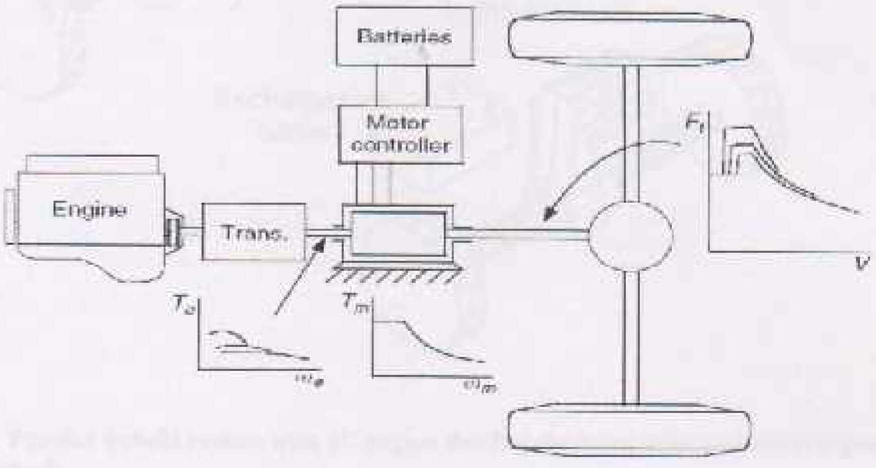


Figure 3.4:Posttransmission single-shaft torque combination parallel hybrid electric drive train

3.2.3 Electric System Drives the Rear Wheels, and the IC Engine the front

The IC engine and the electric machines connectedto different axles, as in figure 3.5. Here the electric system drives the rear wheels, andthe IC engine the front. This is a true parallel hybrid, and the road can be thought of as themedium that connects the two parts of the system, electric and engine. This arrangement has many attractions in terms of simplicity of packaging, and that it is a very neat wayof giving the vehicle a four wheel drive capability. The battery will be mainly charged by regenerative braking, but if that is insufficient, at times of low speed travel the rear wheels could be electrically braked thus charging the battery, and the front driven harderto maintain speed. This transfers energy from the IC engine to the battery, using the road. [5]

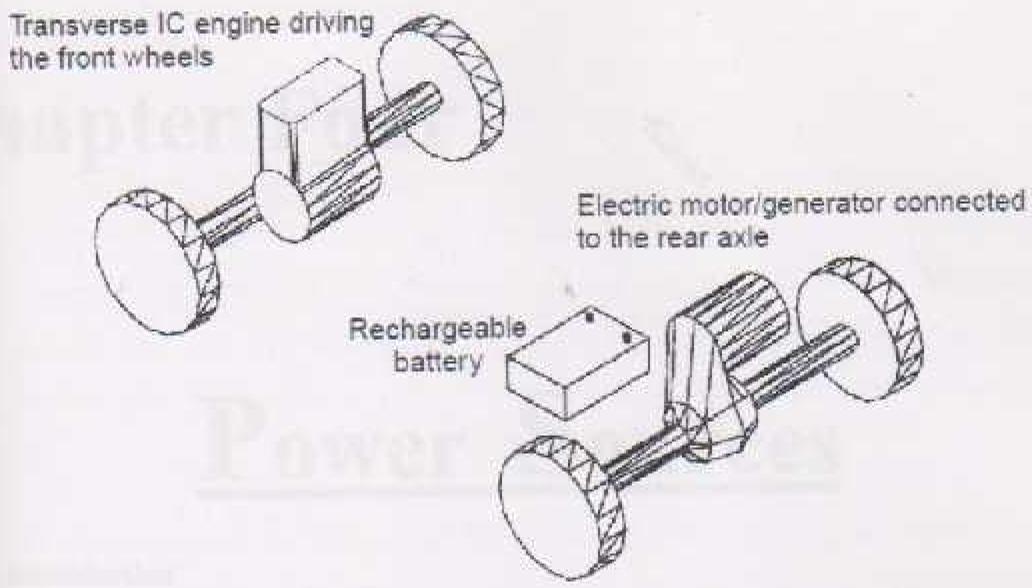


Figure 3.5: Parallel hybrid system with IC engine driving the front axle, and electric power tothe rear wheels

3.5Conclusion

To propose a certain design of parallel hybrid system for the project, many vehicles characteristics must be taken into consideration, including weight of the car,the drive train design in addition to the vehicle function (passenger car, taxi, truck, or bus), and to minimize complex mechanical connections ,and considering the availability of components in the local market .

Chapter Four

Power Sources

4.1 Introduction

Since the beginning of the auto industry the internal combustion engines, was the main source of power for vehicle and the most populate and effective engines gasoline and diesel. They proved their capability over the decades long past and still to this day those which operation by and may will remain for the coming decades, although the energy utilized by burning fuel does not exceed 35-40%, and outputs exhaust harmful to the environment and human.

With the increasing of fuel prices, and the increasing of fuel demand as a result of the huge number of cars on road today all over the word and with the decline in oil inventories in the world, scientists and engineers started to the follow two trends , the first is to increase the efficiency of internal combustion engine, and second finding other sources of kinetic energy for assistance with higher efficiency and non-polluting.

Based on that this research goes for the production of a hybrid car containing two energy sources, the internal combustion engine and electric motor generator.

Parallel hybrid systems, which are most commonly produced at present, have both an internal combustion engine (ICE) and an electric motor connected to a mechanical transmission. Most designs combine a large electrical generator and a motor into one unit, often located between the combustion engine and the transmission, replacing both the conventional starter motor and the alternator. To store power, a hybrid uses a large battery pack with a higher voltage than the normal automotive 12 volts. Accessories such as power steering and air conditioning are powered by electric motors instead of being attached to the combustion engine. This allows efficiency gains as the accessories can run at a constant speed, regardless of how fast the combustion engine is running , shown in figure 4.1.

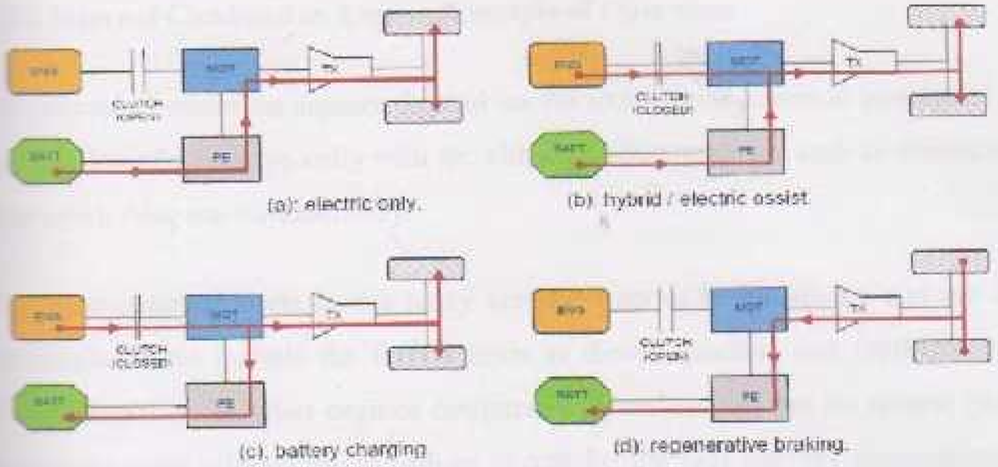


Figure 4.1: Power sources flow.

4.2 Fuel Sources

4.2.1 Internal Combustion Engine

The internal combustion engine is a heat engine in which the burning of a fuel occurs in a confined space called a combustion chamber. This exothermic reaction of a fuel with an oxidizer creates gases of high temperature and pressure, which are permitted to expand. The defining feature of an internal combustion engine is that useful work is performed by the expanding hot gases acting directly to cause movement, for example by acting on pistons, rotors, or even by pressing on and moving the entire engine itself.

This contrasts with external combustion engines such as steam engines which use the combustion process to heat a separate working fluid, typically water or steam, which then in turn does work, for example by pressing on a steam actuated piston.

4.2.2 Internal Combustion Engine Principle of Operation

All internal combustion engines depend on the exothermic chemical process of combustion: the reaction of a fuel, typically with air, although other oxidisers such as nitrous oxide may be employed. Also see stoichiometry.

The most common fuels in use today are made up of hydrocarbons and are derived from petroleum. These include the fuels known as diesel, gasoline and liquified petroleum gas. Most internal combustion engines designed for gasoline can run on natural gas or liquified petroleum gases without modifications except for the fuel delivery components. Liquid and gaseous biofuels, such as Ethanol can also be used. Some can run on Hydrogen, however this can be dangerous. Hydrogen burns with a colorless flame, and modifications to the cylinder block, cylinder head, and head gasket are required to seal in the flame front.

All internal combustion engines must have a means of ignition to promote combustion. Most engines use either an electrical or a compression heating ignition system. Electrical ignition systems generally rely on a lead-acid battery and an induction coil to provide a high voltage electrical spark to ignite the air-fuel mix in the engine's cylinders. This battery can be recharged during operation using an alternator driven by the engine. Compression heating ignition systems, such as diesel engines , rely on the heat created in the air by compression in the engine's cylinders to ignite the fuel.

Once successfully ignited and burnt, the combustion products, hot gases, have more available energy than the original compressed fuel/air mixture (which had higher chemical energy). The available energy is manifested as high temperature and pressure which can be translated into work by the engine. In a reciprocating engine, the high pressure product gases inside the cylinders drive the engine's pistons.

Once the available energy has been removed the remaining hot gases are vented (often by opening a valve or exposing the exhaust outlet) and this allows the piston to return to its previous position (Top Dead Center - TDC). The piston can then proceed to the next phase of its cycle, which varies between engines. Any heat not translated into work is a waste product and is removed from the engine either by an air or liquid cooling system.[9]

4.2.3 Basic Calculations of ICE Indications

4.2.3.1 The Mean Effective Pressure (mep)

The mean effective pressure is a quantity related to the operation of an internal combustion engine and is a valuable measure of an engine's capacity to do work that is independent of engine displacement. When quoted as an indicated mean effective pressure , it may be thought of as the average pressure over a cycle in the combustion chamber of the engine.

The mean effective pressure (mep), which is defined as the work per cycle per displacement:

$$mep = \frac{work\ per\ cycle}{displacement\ of\ cylinder} \quad (4.1)$$

The mean effective pressure can be expressed in terms of torque as :

$$mep\ (kPa) = \frac{2_{\pi}\, n_R T\ (Nm)}{V_d(dm^3)} \quad (4.2)$$

n_R : is the number of revolutions of crankshaft for each power stroke per cylinder (n_R=2 for 4S engines and n_R=1 for two-stroke engines).[2]

T : is the torque in Nm.

V_d : the engine displacement cc.

4.2.3.2 Engine Performance Parameters

The practical engine performance parameters of interest are power, torque, specific fuel consumption, and specific emissions. The power of the 4S engine can be expressed as numerical equation :

$$P = \frac{Vd \times mep \times n}{600 \times k} \quad (4.3) \quad [7]$$

mep = mean effective pressure.

n = Engine speed

k = 2 for four stroke engine

The torque, T, is given by :

$$T = \frac{mep\, V_d}{4\pi} \quad (4.4)$$

4.2.3.3 Design of Engine Power Capacity

The engine should be able to supply sufficient power to support the vehicle operation at normal constant speeds both on a flat and a mild grade road without the help of the electric motors , at the same time, the engine should be able to produce an average power that is larger than the average load power when the vehicle operates with a stop-and-go operating pattern. As a requirement of normal highway driving at constant speed on a flat or a mild grade road, the power needed is expressed as

$$P_e = \frac{V}{1000\eta_{t,e}}\left(M_v\, g\, f_r + \frac{1}{2}\rho_a C_D A_f V^2 + M_v\, g\, i\right)(kW) \quad (4.5)$$

The parameters of a passenger car are used in the calculations. These parameters are

P_e: power needed

M_v= vehicle mass ,

f_r= rolling resistance coefficient

ρ_a= air density

A_f = front area

C_D = aerodynamic drag coefficient

$\eta_{t,e}$= transmission efficiency from engine to drive wheels

g = acceleration of gravity. [2]

4.3 Electrical Sources

4.3.1 Battery

A basic requirement for electric vehicles (EVs) is a portable source of electrical energy, which is converted to mechanical energy in the electric motor for vehicle propulsion. Electrical energy is typically obtained through conversion of chemical energy stored in devices such as batteries and fuel cells. A flywheel is an alternative portable source in which energy is stored in mechanical form to be converted into electrical energy on demand for vehicle propulsion. The portable electrical energy source presents the biggest obstacle in commercialization of EVs. A near-term solution for minimizing the environmental pollution problem due to the absence of a suitable, high-energy-density energy source for EVs is perceived in the hybrid electric vehicles (HEVs) that combine propulsion efforts from gasoline engines and electric motors.

The batteries are made of unit cells containing the chemical energy that is convertible to electrical energy. One or more of these electrolytic cells are connected in series to form one battery. The grouped cells are enclosed in a casing to form a battery module. A battery pack is a collection of these individual battery modules connected in a series and parallel combination to deliver the desired voltage and energy to the power electronic drive system

4.3.1.1 Lead Acid Batteries

Lead acid batteries are well established commercially with good backup from industry. They are the cheapest rechargeable batteries per kilowatt-hour of charge, and will remain so for the foreseeable future. However, they have low specific energy and it is hard to see how a long-range vehicle can be designed using a lead acid battery. Lead acid will undoubtedly continue for some considerable time to be widely used for short-range vehicles. Lead acid batteries have a greater range of efficient specific powers than many other types and so they are very much in contention in hybrid electric vehicles, where only a limited amount of energy is stored, but it should be taken in and given out quickly.

4.3.1.2 Battery Capacity

One factor rating a battery is capacity, C, with units of ampere hour (Ah). A rechargeable NiMH battery in the AA size has capacity equal to 2.5 Ah. For discussion, assume the battery current, I, is 0.5 A. The time, t,

that the battery can operate before it goes dead is

$$t = \frac{C}{I} \quad (4.6)$$

C : Battery capacity.
t : Time
I : Battery current.

The preceding calculation applies to a perfect battery and does not take into account the decline of terminal voltage.
Cell capacity, C, is determined partially by the mass of available reactants. The capacity of a perfect battery in either series or parallel assembly of cells is derived below. Let C_o be the capacity of a cell. Let V_o be the cell voltage. The energy of a cell, E0, is the product.

$$E_0 = C_0\, V_0 \quad (4.7)$$

E_0: the energy of a cell.
C_0: the capacity of a cell.
V_0: the cell voltage.
Consider a battery with N cells. The energy of the battery, E, is

$$E_0 = N\, C_0\, V_0 \quad (4.8)$$

If connected in series, that is, end-to-end, the battery voltage is

$$V = NV_0 \qquad (4.9)$$

The energy of the battery connected in series is

$$E_0 = (N\,V_0)C_0 = V\,C_0 \qquad (4.10)$$

When connected in series, the capacity of a battery is the same as the capacity of a cell. If connected in parallel, the battery voltage equals that of a cell, that is, V = V_0.
The energy of the battery connected in parallel is

$$E_0 = (N\,C_0)V_0 = C\,V_0 \qquad (4.11)$$

For a parallel connection, the battery capacity, C, is equal to $N\,C_0$. Compare battery energy for series and parallel connections; the equations are almost the same.[1]

4.3.2 Inverter and Driver

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the resulting AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.

Static inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.

The electrical inverter is a high-power electronic oscillator. It is so named because early mechanical AC to DC converters were made to work in reverse, and thus were "inverted", to convert DC to AC, show in figure 4.2 .[11]

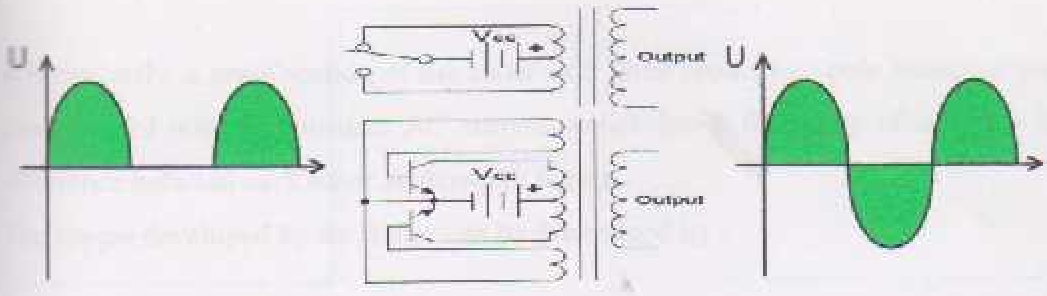


Figure 4.2: DC\AC Inverter

4.3.3 Induction Motor Drives

Commutatorless motor drives offer a number of advantages over conventional DC commutator motor drives for the electric propulsion of EVs and HEVs. At present, induction motor drives are the mature technology among commutatorless motor drives. Compared with DC motor drives, the AC induction motor drive has additional advantages such as lightweight nature, small volume, low cost, and high efficiency.

These advantages are particularly important for EV and HEV applications. there are two types of induction motors, namely, wound-rotor and squirrel cage motors. Because of the high cost, need for maintenance, and lack of sturdiness, wound-rotor induction motors are less attractive than their squirrel-cage counterparts, especially for electric propulsion in EVs and HEVs. Hence, squirrel-cage induction motors are loosely termed as induction motors. Show figure 4.3 .

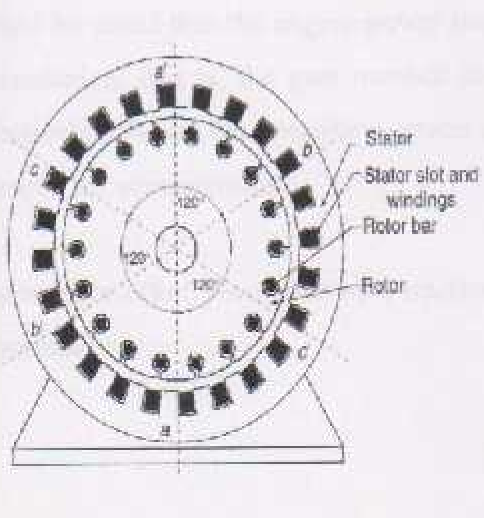


Figure 4.3 : Cross-section of an induction motor

schematically, a cross section of the stator of a three phase, two-pole induction motor. Each phase is fed with a sinusoidal AC current, which has a frequency of ω and a 120° phase difference between each other as shown in Figure .

The torque developed by the motor can be determined by :

$$T = \frac{P_{mech}}{\omega_m} \quad (4.12)$$

P_{mech} : mechanical power , ω_m: motor speed

the motor power rating is expressed as :

$$P_m = \frac{\delta_m M_v}{2\,\eta_{t,m}\,t_a}\left(V_f^2 + V_b^2\right). \quad (4.13)$$

δ_m : mass factor .

M_v : vehicle Wight .

$\eta_{t,m}$: Transmission efficiency .

V_f: maximum speed .

V_b: base speed .

t_a : acceleration time

It should be noted that the motor power obtained above is somewhat overestimated. Actually, the engine has some remaining power to help the electric motor to accelerate the vehicle It should be noted that the engine power transmitted to the driven wheels is associated with the transmission, that is, the gear number and gear ratios it that a multigear transmission will effectively increase the remaining power at the driven wheels, thus reducing the motor power required for acceleration.[3]

The tractive effort developed by a traction motor on driven wheels and the vehicle speed are expressed as :

$$F_t = \frac{T_m\, i_g i_0 \eta_t}{r_d} \qquad (4.10)$$

And

$$V = \frac{\pi\, N_m r_d}{30\, i_g\, i_0}(m\backslash s) \qquad (4.11)$$

F_t : tractive effort .

V : vehicle speed .

Tm : motor torque output .

Nm : speed in rpm .

i_g : the gear ratio of transmission .

i_0 : the gear ratio of final drive .

r_d : the radius of the drive wheels.

η_t : the efficiency of the whole driveline from the motor to the driven wheels .

4.3.4 Regenerative Braking System(RBS)

Most HEVs employ both a conventional braking system and a RBS. The conventional braking system typically includes frictional drum or disc braking assemblies selectively actuated by a hydraulic system. The RBS utilizes the electric motor, providing negative torque to the driven wheels and converting kinetic energy to electrical energy for recharging the battery or power supply. The dissipation of kinetic energy during braking, by an electric or hybrid vehicle can be recovered advantageously by controlling power electronics such that the electric traction motor behaves as a generator. The energy recovered during this process can be returned to the energy storage device for future use. As shown in figure 4.4 [7]

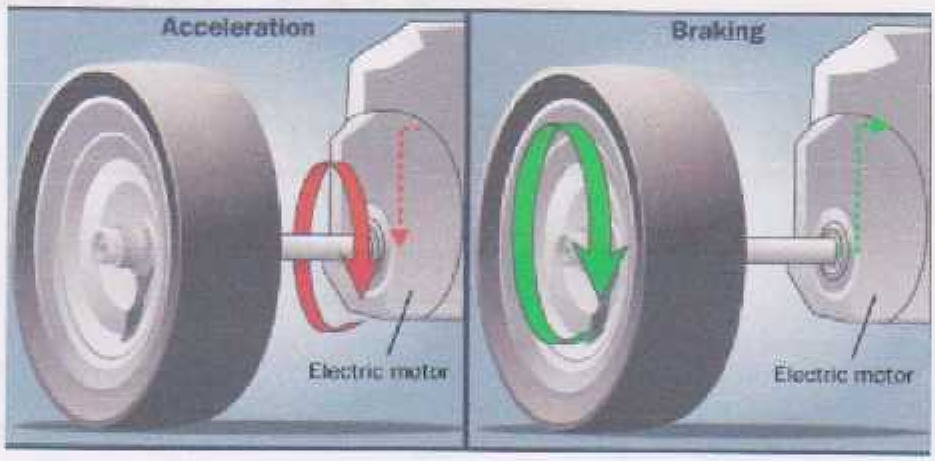


Figure 4.4: Regenerative Braking power flow

Regenerative Braking Proved its effectiveness depended on drive cycle and the percentage of the negative torque of the wheels to the electric motor to generate more electric power to the batteries, that depends on the area where the vehicle is moving.

4.3.5 Rectifier

A rectifier is an electrical device that converts alternating current (AC) to direct current (DC), a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components.

A device which performs the opposite function (converting DC to AC) is known as an inverter, as shown in figure 4.5 : [10]

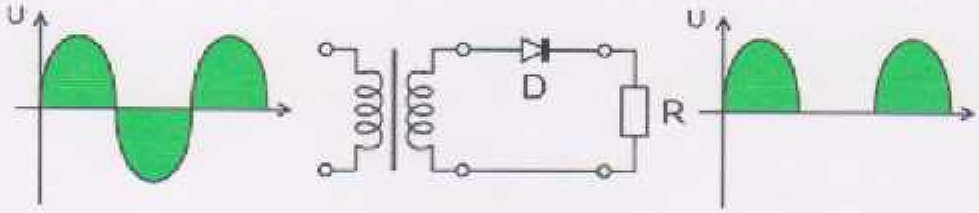


Figure 4.5:Rectifier wave

Chapter Five

Drive Train Modeling and Design Plan

5.1 Introduction

Design methodology for one particular configuration may be not applicable to other configurations and the design result for a particular configuration may be applicable for only a given operation environment and mission requirement. This chapter will focus on the design methodology of parallel drive trains with torque coupling, which operate on the electrically peaking principle that is, the engine supplies its power to meet the base load (operating at a given constant speed on flat and mild grade roads, or at the average of the load of a stop-and-go driving pattern) and the electrical traction supplies the power to meet the peaking load requirement.

5.2 Maximum State-of-Charge of Peaking Power Source (Max. SOC-of- PPS) Control Strategy

When a vehicle is operating in a stop-and-go driving pattern, the PPS must deliver its power to the drive train frequently. Consequently, the PPS tends to be discharged quickly. In this case, maintaining a high SOC in the PPS is necessary to ensure vehicle performance. Thus, the maximum SOC of the PPS control strategy may be the proper option. The maximum control strategy can be explained by figure 5.1. In this figure, the maximum power curves for hybrid traction (engine plus electric motor), engine-alone traction, electric motor-alone traction, and regenerative braking.[2]

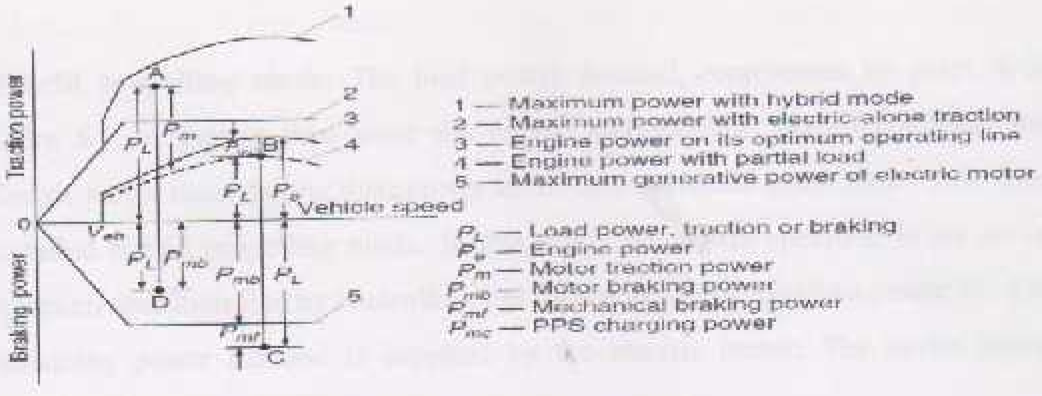


Figure 5.1: Various operating modes based on power demand

5.3 The operation modes of the drive train in parallel hybrid vehicle

Motor-alone propelling mode: The vehicle speed is less than a preset value vehicle speed below V_{eb}, which is considered to be the bottom line of the vehicle speed below which the engine cannot operate steadily. In this case, the electric motor alone delivers its power to the driven wheels, while the engine is shut down or idling. The engine power, electric traction power, and the PPS discharge power can be written as :

$$Pe = 0 \qquad (5.1)$$

$$P_m = \frac{PL}{\eta_{t,m}} \qquad (5.2)$$

Where

PL = V* I (W)

$$P_{pps\_d} = \frac{P_m}{\eta_m} \qquad (5.3)$$

Pe : is the engine power output. η_m : is the motor efficiency.

PL : is the load power demand on the drive wheels.

$\eta_{t,m}$: is the transmission efficiency from the motor to the driven wheels.

P_m : is the power output of the electric motor.

P_{pps_d} : is the PPS discharge power.

Hybrid propelling mode: The load power demand, represented by point A in figure 5.1, is greater than what the engine can produce, both the engine and electric motor must deliver their power to the driven wheels at the same time. This is called hybrid propelling mode. In this case, the engine operation is set on its optimum operation line by controlling the engine throttle to produce power Pe. The remaining power demand is supplied by the electric motor. The motor power output and PPS discharge power are

$$Pm = \frac{P_l - P_e \, \eta_{t,e}}{\eta_m} \qquad (5.4)$$

Where $Pe = \frac{mep \; Ap \; Sp}{4}$

$$P_{pps\_d} = \frac{Pm}{\eta_m} \qquad (5.5)$$

$\eta_{t,e}$: is the transmission efficiency from the engine to the drive wheels.

PPS charge mode: When the load power demand, represented by point B in figure 5.1. is less than the power that the engine can produce while operating on its optimum operation line, and the PPS SOC is below its top line, the engine is operated on its optimum operating line, producing its power Pe. In this case, the electric motor is controlled by its controller to function as a generator, powered by the remaining power of the engine. The output power of the electric motor and PPS charge power are

$$Pm = \left(Pe - \frac{PL}{\eta_{t,e}}\right) \eta_{t,e,m} * \eta_m \qquad (5.6)$$

$$P_{pps-c} = Pm \qquad (5.7)$$

$\eta_{t,e,m}$:is the transmission efficiency from the engine to the electric motor.

Engine-alone propelling mode: When the load power demand (represented by point B in figure 5.1) is less than the power that the engine can produce while operating on its optimum operation line, and the PPS SOC has reached its top line, the engine-alone propelling mode is used. In this case, the electric system is shut down, and the engine is operated to supply the power that meets the load power demand. The power output curve of the engine with a partial load is represented by the dashed line in figure 5.1. The engine power, electric power, and battery power can be expressed by

$$Pe = \frac{PL}{\eta_{t,e}} \tag{5.8}$$

$$P_m = 0, \tag{5.9}$$

$$P_{pps} = 0. \tag{5.10}$$

Regenerative-alone brake mode: When the vehicle experiences braking and the demanded braking power is less than the maximum regenerative braking power that the electric system can supply (as shown in figure 5.1 by point D), the electric motor is controlled to function as a generator to produce a braking power that equals the commanded braking power. In this case, the engine is shut down or set idling. The motor power output and PPS charge power are

$$P_{mb} = PL\eta_{t,m} * \eta_m, \tag{5.11}$$

$$P_{pps\text{-}c} = P_{mb}. \tag{5.12}$$

Hybrid braking mode: When the demanded braking power is greater than the maximum regenerative braking power that the electric system can supply (as shown in figure 5.1 by point C), the mechanical brake must be applied. In this case, the electric motor should be controlled to produce its maximum regenerative braking power, and the mechanical brake system should handle the remaining portion.[2]

The motor output power, battery charging power, and mechanical braking power are :

$$P_{mb} = P_{mb,max} * \eta_{m.} \qquad (5.13)$$

$$P_{pps\text{-}c} = P_{mb}. \qquad (5.14)$$

5.4 Design of Drive Train Parameters

The parameters of the drive train such as engine power, electric motor power, gear ratios of transmission, and power and energy capacity of the peaking power source are key parameters, and exert a considerable influence on vehicle performance and operation efficiency. However, as initial steps in the design, these parameters should be estimated based on performance requirements.

In the following sections, the parameters of a passenger car which used as a prototype for implementation the proposed system . These parameters are vehicle mass M_v=1500 kg, rolling resistance coefficient f_r=0.01, air density ρ_a=1.205 kg/m3, front area A_f =2.0 m2, aerodynamic drag coefficient C_D=0.3, radius of driven wheels r =0.2794 m, and transmission efficiency from engine to drive wheels $\eta_{t,e}$=0.9, and from motor to drive wheels $\eta_{t,m}$=0.95.

5.4.1 Design of Engine Power Capacity

The engine should be able to supply sufficient power to support the vehicle operation at normal constant speeds both on a flat and a mild grade road without the help of the PPS. At the same time, the engine should be able to produce an average power that is larger than the average load power when the vehicle operates with a stop-and-go operating pattern.

As a requirement of normal highway driving at constant speed on a flat or a mild grade road, the power needed is expressed as :

$$P_e = \frac{V}{1000\eta_{t,e}}\left(M_v\, g\, f_r + \frac{1}{2}\rho_a C_D A_f V^2 + M_v\, g\, i\right)(kW) \qquad (5.15)$$

The above-designed engine power should be evaluated so that it meets the average power requirement while driving in a stop-and-go pattern. In a drive cycle, the average load power of a vehicle can be calculated by :

$$P_{ave} = \frac{1}{T}\int_0^T \left(M_v\, g\, f_r V + \frac{1}{2}\rho_a C_D A_f V^3 + \delta\, M_v\, V\, \frac{dV}{dt}\right)(dt) \qquad (5.16)$$

T: is the total time in drive cycles.

The average power varies with the degree of regenerative braking. The two extreme cases are the full and zero regenerative braking cases. Full regenerative braking recovers all the energy consumed in braking and the average power is calculated by equation (5.16). However, when the vehicle has no regenerative braking, the average power is larger than that with full regenerative braking, which can be calculated from equation (5.16) in such a way that when the instantaneous power is less than zero, it is given a zero.

In the engine power design, the average power that the engine can produce must be greater than the average load power. In a parallel drive train, the engine is mechanically coupled to the driven wheels. Hence, the engine rotating speed varies with the vehicle speed.

5.4.2 Calculation of Vehicle Fuel Economy

Vehicle fuel economy can be calculated by finding the load power and the specific fuel consumption of the engine. The engine power output Point him in the Equation (5.16) , The engine speed, related to vehicle speed and gear ratio, can be expressed as :

$$N_e = \frac{30\, V\, i_g i_o}{\pi\, r_d} \qquad (5.17)$$

After determination of the engine power and speed by equation (5.16) and (5.17), the value of the specific fuel consumption, can be found in the graph of the engine fuel economy characteristics as shown in figure 5.2

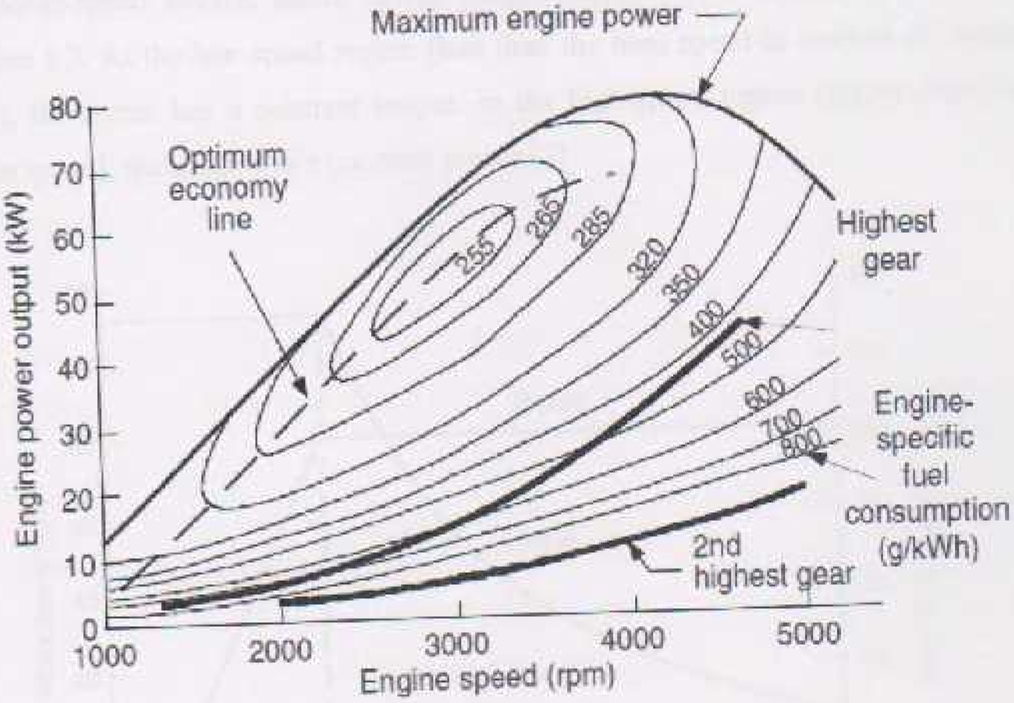


Figure 5.2: Fuel economy characteristics of a typical ICE

5.4.3 Design of Electric Motor Drive Power Capacity

In HEV, the major function of the electric motor is to supply peak power to the drive train. In the motor power design, acceleration performance and peak load power in typical drive cycles are the major concerns.

As an initial estimate, one can make the assumption that the steady-state load (rolling resistance and aerodynamic drag) is handled by the engine and the dynamic load (inertial load in acceleration) is handled by the motor.

The total tractive power for accelerating the vehicle from zero to speed Vf in ta seconds can be finally obtained as :

$$P_t = \frac{\delta M_v}{2t_a}(V_f^2 + V_b^2) + \frac{2}{3}M_v g f_r V_f + \frac{1}{5}\rho_a C_D A_f V_f^3 \qquad (5.18)$$

The motor which is needed must have a rated power as result of the equation. Variable-speed electric motor drives usually have the characteristics shown in figure 5.3. At the low-speed region (less than the base speed as marked in figure 5.3), the motor has a constant torque. In the high-speed region (higher than the base speed), the motor has a constant power.[2]

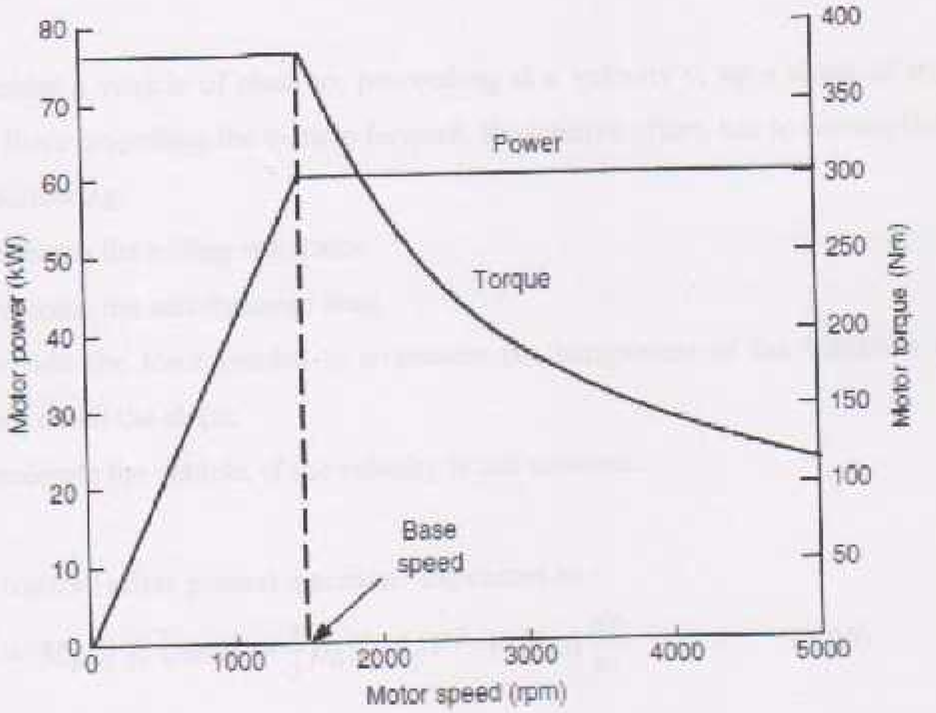


Figure 5.3: Typical variable-speed electric motor characteristics

The torque of the electric motor can be calculated by

$$T = P/\omega \qquad (5.19)$$

P is a power rated .

ω is a speed of a motor in (rpm).

ω critical = P_{rated} / T_{max}

ω critical is the is the last motor speed in (rpm) the motor remains at highest torque.

5.5 Power Train Tractive Effort and Vehicle Speed design

The first step in vehicle performance modeling is to produce an equation for the tractive effort. This is the force propelling the vehicle forward, transmitted to the ground through the drive wheels.

Consider a vehicle of mass m, proceeding at a velocity v, up a slope of angle ψ. The force propelling the vehicle forward, the tractive effort, has to accomplish the following:

- overcome the rolling resistance.
- overcome the aerodynamic drag.
- provide the force needed to overcome the component of the vehicle's weight acting down the slope.
- accelerate the vehicle, if the velocity is not constant.

the tractive effort general equation expressed as :

$$F_t = M_v\, g\, f_r \cos\alpha + \frac{1}{2}\rho_a C_D A_f V^2 + M_v \delta \frac{dV}{dt} \qquad (5.20)$$

consider each of these parameters in turn

5.5.1 Rolling Resistance

The rolling resistance is primarily due to the friction of the vehicle tire on the road the rolling resistance expressed as :

$$F_{rr} = \mu Mg \qquad (5.21)$$

Where μ =0.015 for a radial tire , g = 9.81 $m/_{s^2}$, M = total weight of the vehicle

5.5.2 Aerodynamic Drag

The force is due to the friction of the vehicle of the vehicle body moving through the air .

$$F_{ad} = \frac{1}{2}\rho A C_d V^2 \qquad (5.22)$$

ρ : is the density of the air

A : is the frontal area for the vehicle

C_d : is the a constant called the drag coefficient

V : is the velocity

5.5.3 Hill Climbing Force

The force need to drive the vehicle up a slope , it is simply the component of the vehicle weight that that acts along the slope. by simple resolution of forces we see that :

$$F_{hc} = mg\sin(\varphi) \qquad (5.23)$$

5.5.4 Acceleration Force

If the velocity of the vehicle is changing, then clearly a force will need to be applied in addition to the forces. This force will provide the linear acceleration of the vehicle, and is given by the well-known equation derived from Newton's second law,

$$F_{la} = ma$$

The tractive effort delivered by the power train , if G is the gear ratio of the system connecting the motor to the axle , and T is the motor torque .can expressed by .

$$T = Fte * \frac{r}{G}$$

$$Fte = \frac{G}{r} T \qquad (5.23)$$

Where vehicle speed could be obtained from the following eq.

$$V = V_e * 60\ 2\pi\ \frac{r}{G} \qquad (5.25)$$

V_e =engine speed (rpm)

r = tire radius

G = overall gear ratio

From the above equation we can calculate the max speed

But by combining the tractive effort of the electric motor over the road speed diagram with the aerodynamic drag force and rolling resistance force diagram the result will as the chart like figure 5.4

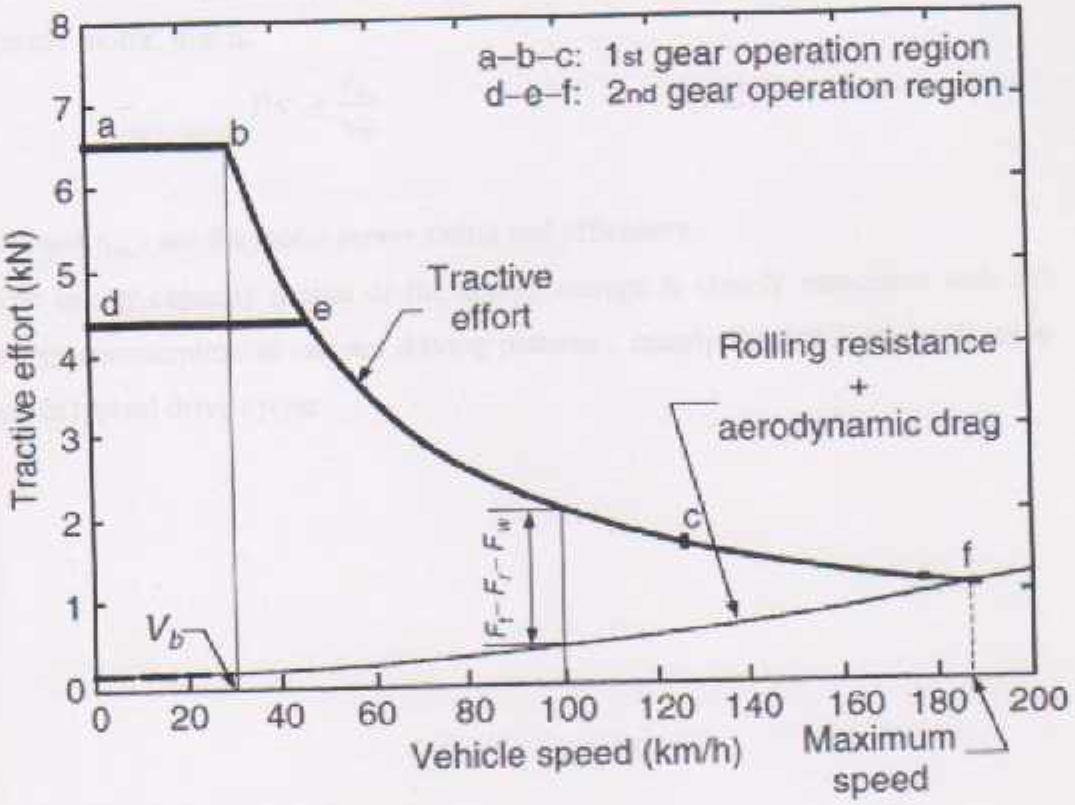


Figure 5.4: Tractive effort VS. vehicle speed with a traction motor and two-gear transmission

5.5.5 Total Tractive Effort

The total tractive effort is the sum of all these forces:

$$F_{te} = F_{rr} + F_{ad} + F_{hc} + F_{la} + F_{\omega a} \qquad (5.26)$$

F_{rr} : is the rolling resistance force,

F_{ad} : is the aerodynamic drag,

F_{hc} : is the hill climbing force,

F_{la}: is the force required to give linear acceleration, [5]

5.6 Energy Storage Design

The energy storage design mainly includes the design for the power and energy capacity. The power capacity design is somewhat straightforward. The terminal power of the energy storage must be greater than the input electric power of the electric motor, that is,

$$Ps \geq \frac{P_m}{\eta_m} \qquad (5.27)$$

P_m and η_m : are the motor power rating and efficiency.

The energy capacity design of the energy storage is closely associated with the energy consumption in various driving patterns , mainly the full load acceleration and in typical drive cycles.

Chapter Six

Control Strategy

6.1 Introduction .

6.2 Sensors .

6.2.1 Vehicle Speed Sensor .

6.2.1.1 Hall EffectSensor .

6.2.1.2 Inductive Speed Sensor .

6.2.2 Battery Voltage .

6.2.3 Signal of Accelerator Pedal .

6.2.3.1Throttle Position Sensor (TPS) .

6.2.4Gear Shift Sensor

6.3 Controller

6.3.1 PICController .

6.4 Calibration and programming .

6.1 Introduction

The main available operation modes in a parallel hybrid drive train (PHEV) mainly include :

(1) engine-alone traction.

(2) electric-alone traction.

To achieve the best operationof the proposed system in various operating conditions, input information is entered to controller which will function to achieve the best operation of various outputs to control the system .

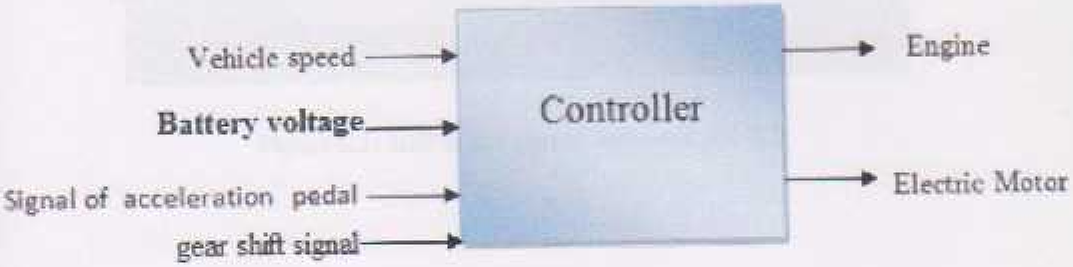


Figure6.1: Block diagram for control system

6.2 Sensors

6.2.1Vehicle Speed Sensor

6.2.1.1Hall EffectSensor

Is a transducer that varies its output voltage in response to changes in magnetic field. Hall sensors are used for proximity switching, positioning, speed detection, and current sensing applications.

Hall sensors are commonly used to time the speed of wheels and shafts, such as for internal combustion engine ignition timing or tachometers. They are used in brushless DC electric motors to detect the position of the permanent magnet. In the pictured wheel carrying two equally spaced magnets, the voltage from the sensor will peak twice for each revolution. This arrangement is commonly used to regulate the speed of disc drive.

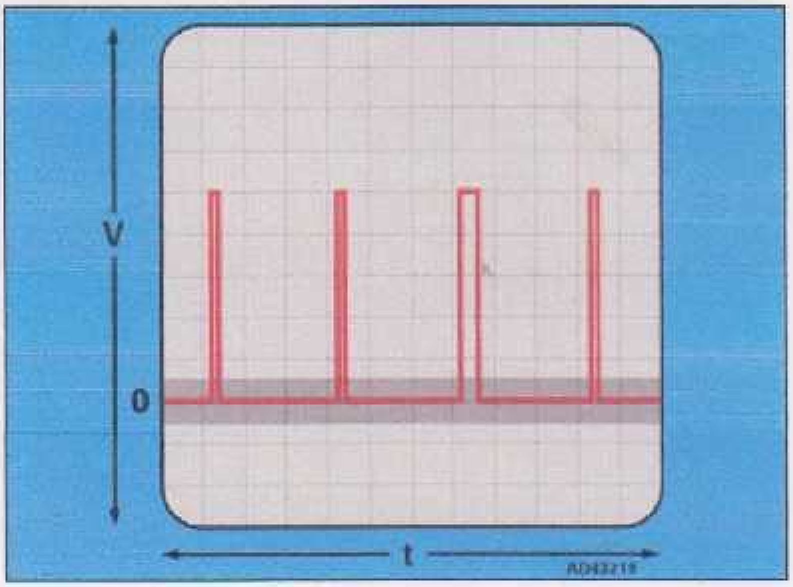


Figure 6.2: Hall effect sensor wave out put [12]

6.2.1.2 Inductive Speed Sensor

This sensor is designed for incremental measurement of rotational speed (e.g. crankshaft or wheelspeed). The inductive sensor consists of a bar magnet with a soft magnetic pole pin supporting an induction coil with two connections. When a ferromagnetic ring gear turns past this sensor, it generates a voltage in the coil which is directly proportional to the periodic variation in the magnetic flux. The rotational speed is reflected on a periodic interval between the voltage's zero transition points. The main benefit of this sensor is the combination of a high quality production part and robust, high temperature resistance. Additionally the installation depth can be changed according to the customer request.

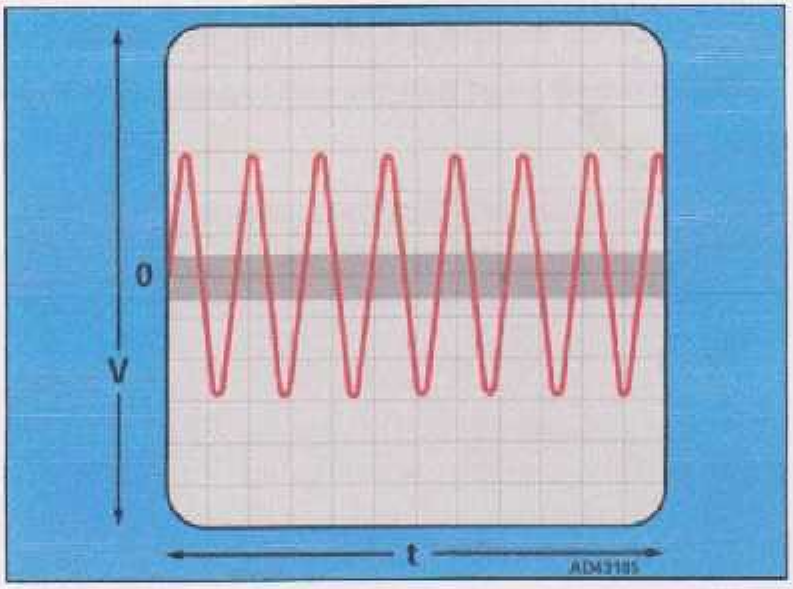


Figure6.3:Inductive Speed Sensor wave output [12]

6.2.2 Battery Voltage

A voltmeter is an instrument used for measuring the electrical potential difference between two points in an electric circuit. Analog voltmeters move a pointer across a scale in proportion to the voltage of the circuit; digital voltmeters give a numerical display of voltage by use of an analog to digital converter.

6.2.3 Signal of Accelerator Pedal

The accelerator pedal module converts the driver's accelerator pedal effort to an electric signal, and sends the signal to the engine ECU, which controls engine power and acceleration.

6.2.3.1Throttle Position Sensor (TPS)

Is a sensor used to monitor the position of the throttle in an internal combustion engine. The sensor is usually located on the butterfly spindle so that it can directly monitor the position of the throttle valve butterfly.

The sensor is usually a potentiometer, and therefore provides a variable resistance dependent upon the position of the valve (and hence throttle position).

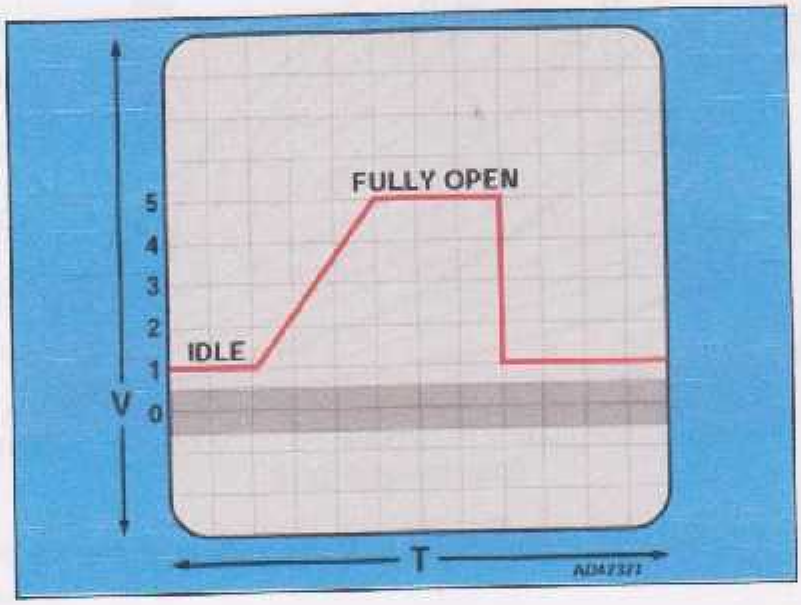


Figure 6.4:Throttle position sensor signal [12]

6.2.5Gear shift Signal

This signal send to controller to Determine the best Cases of vehicle to reduce fuel consumption among the bestgear ratio , the programming controller control when the ICE start on and off according to the best cases to reduce fuel consumption.as shown in the Figure 6.5.

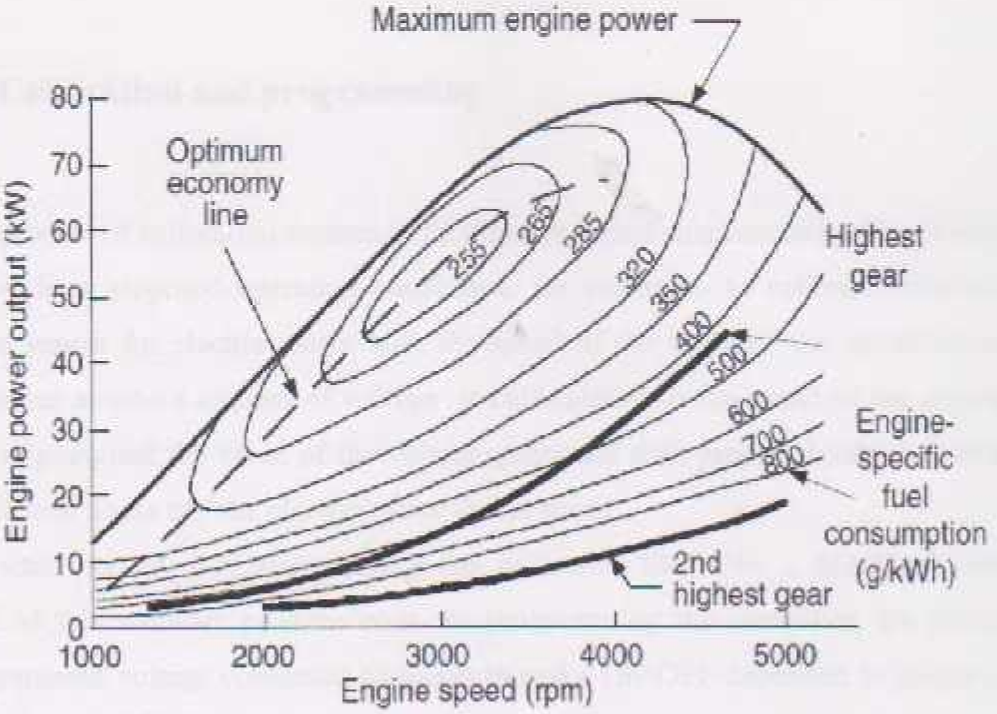


Figure 6.5:Operating point of an engine at constant speed with highest gear and second highest gear.

6.3 Controller

6.3.1 PIC -Programmable Interface Controller.

PIC is a family of harvard architecture micro controllers made by Microchip Technology, derived from the PIC originally developed by General Instrument's Microelectronics Division .The name PIC initially referred to "Programmable Interface Controller.

PICs are popular with both industrial developers and hobbyists like due to their low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools, and serial programming (and re-programming with flash memory) capability.Microchip and inverter device is capability to re-programming and will used in hybrid car to control of variesoperation condition.

6.4 Calibration and programming

The process of calibration sensors to facilitate programming controller, depends on the various proposed operating conditions, for example:- to calibrate inductive speed sensor for electric motor with the speed of the vehicle, the speed sensor generates a certain amount of voltage is calibrated with the speed of the vehicle are programmed the value of the voltage generated with proposed vehicle speed, which will Shutc off the electric motor at this speed .

Software needed for programming the controller like C++ , MATLAP and MPLAP,this software produce cods for programming the controller, the output programmed voltage connected to relays to make ON\OFF depended to proposed operation condition .

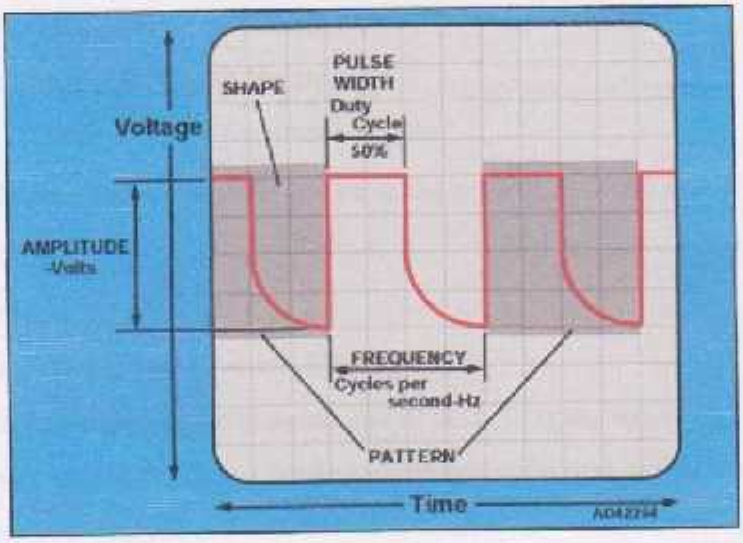


Figure6.6:Voltage wave parameter used in celebration and programming [12]

Chapter Seven

Project Calculation and Building

7.1 Introduction

The project will be implemented on four-wheel drive(4WD)vehicle with diesel engine, electric machines will be incorporated to drive rear axle, as in figure 3.5 shown in chapter 3. Here the electric system drives the rear wheels, andthe IC engine the front. This is a true parallel hybrid electric vehicle , and the road medium connects the two drive sources, electric and engine, that giving the vehicle a four wheel drive capability. The vehicle can be traveled by IC engine in front axle in specified operation condition , and On the other handcan be traveled by electric motor by using rear axle at low speed at city drive cycle. The battery will be chargedby regenerative braking,at times of low speed travel the rearwheels could be electrically braked thus charging the battery(regenerative braking), and if travelled the front axle by IC engine ,the battery will becharged by motor as generator ,This transfers energy from the IC engine to the batteryusing the road.

The vehicle was chosen for the project, Mitsubishi L200,figure 7.1, because it has two drive axles front and rear, the parameters and specifications of this four-wheel drivevehicle which used as a prototype for implementation the proposed system are as followsintable 7.1.

Table 7.1 specifications of Mitsubishi L200four-wheel drivevehicle

Engine	Double Cab 2.5 TD
Engine type	4 cycle, 4 cylinder, in-line, OHC intercooled, turbocharged diesel
Cubic (cm3)	2477
Compression Ratio	21.0:1
Bore / stroke (mm)	91.1 x 95.0
Torque N.m	240
at rpm	2,000
First gear	3.918
Second gear	2.261
Third gear	1.395
Fourth gear	1.000

Fifth gear	0.829
Reverse gear	3.952
FD	4.2
High Gear	1.000
Low Gear	1.925
Over all length (mm)	5,010
Over all width (m)	1,5
Over all height (m)	1,5
Wheelbase (mm)	2,960
Front track	1,465
vehicle mass M_v kg	1650 +350 kg(electric motor +battery +passengers)
Mass factor	1.25
rolling resistance coefficient f_r	0.013
air density ρ_a kg/m3	1.205
front area A_f m2	1.9 A= 0.8 × Track × height =1.5*1.6
aerodynamic drag coefficient C_D	0.45
radius of driven wheels (r) m	0.35
and transmission efficiency from engine to drive wheels $\eta_{t,e}$	0.9
and from motor to drive wheels $\eta_{t,m}$	0.95

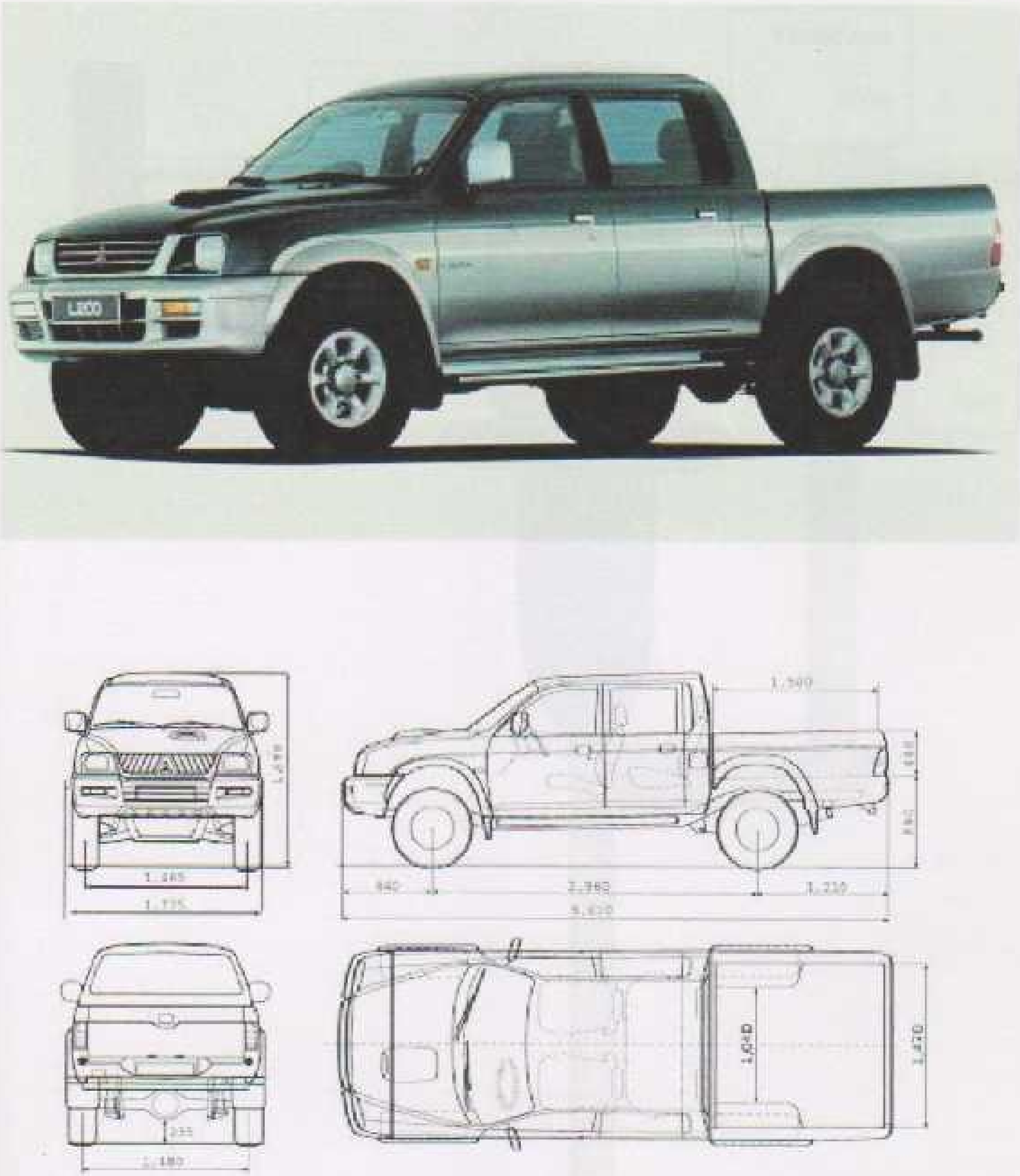
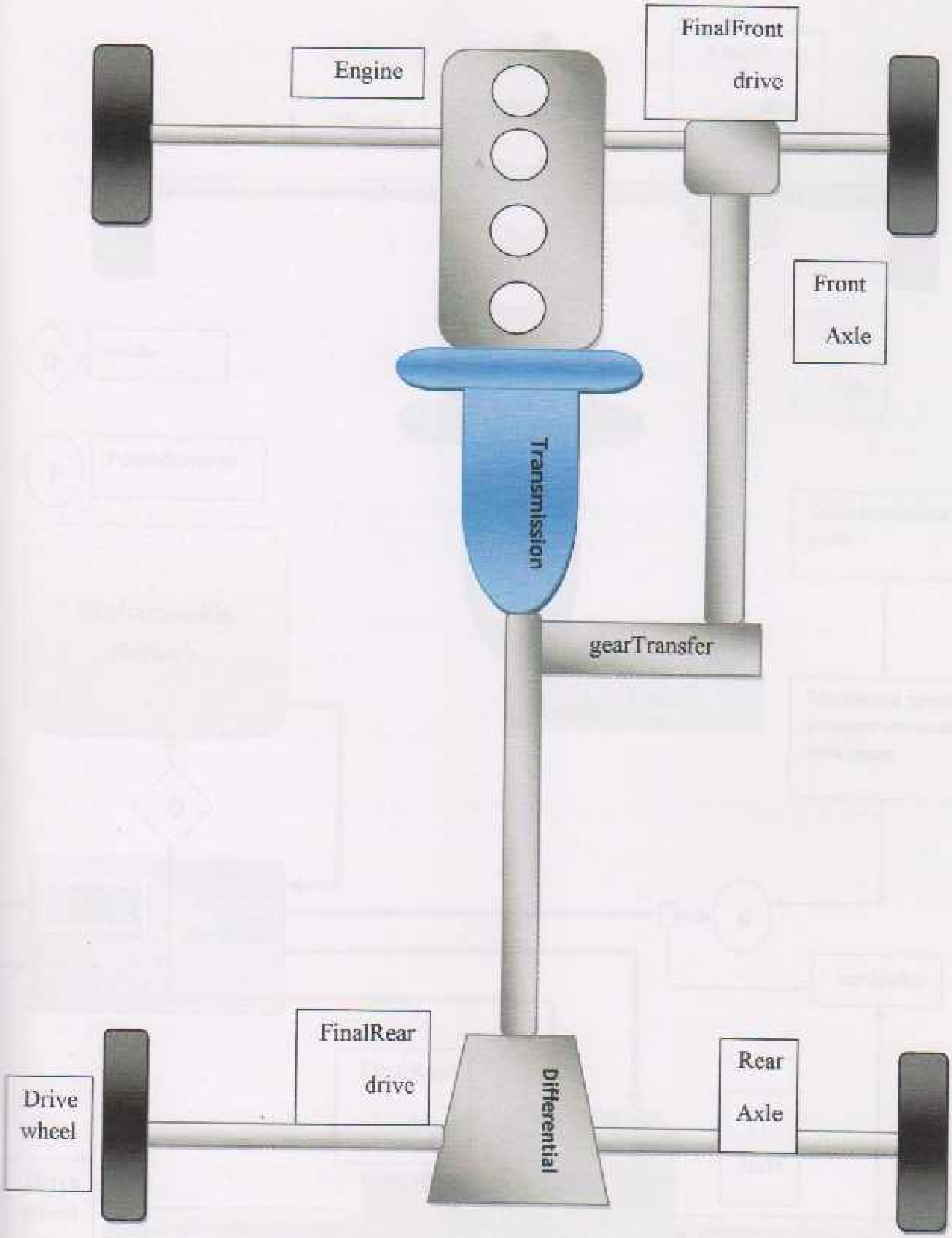
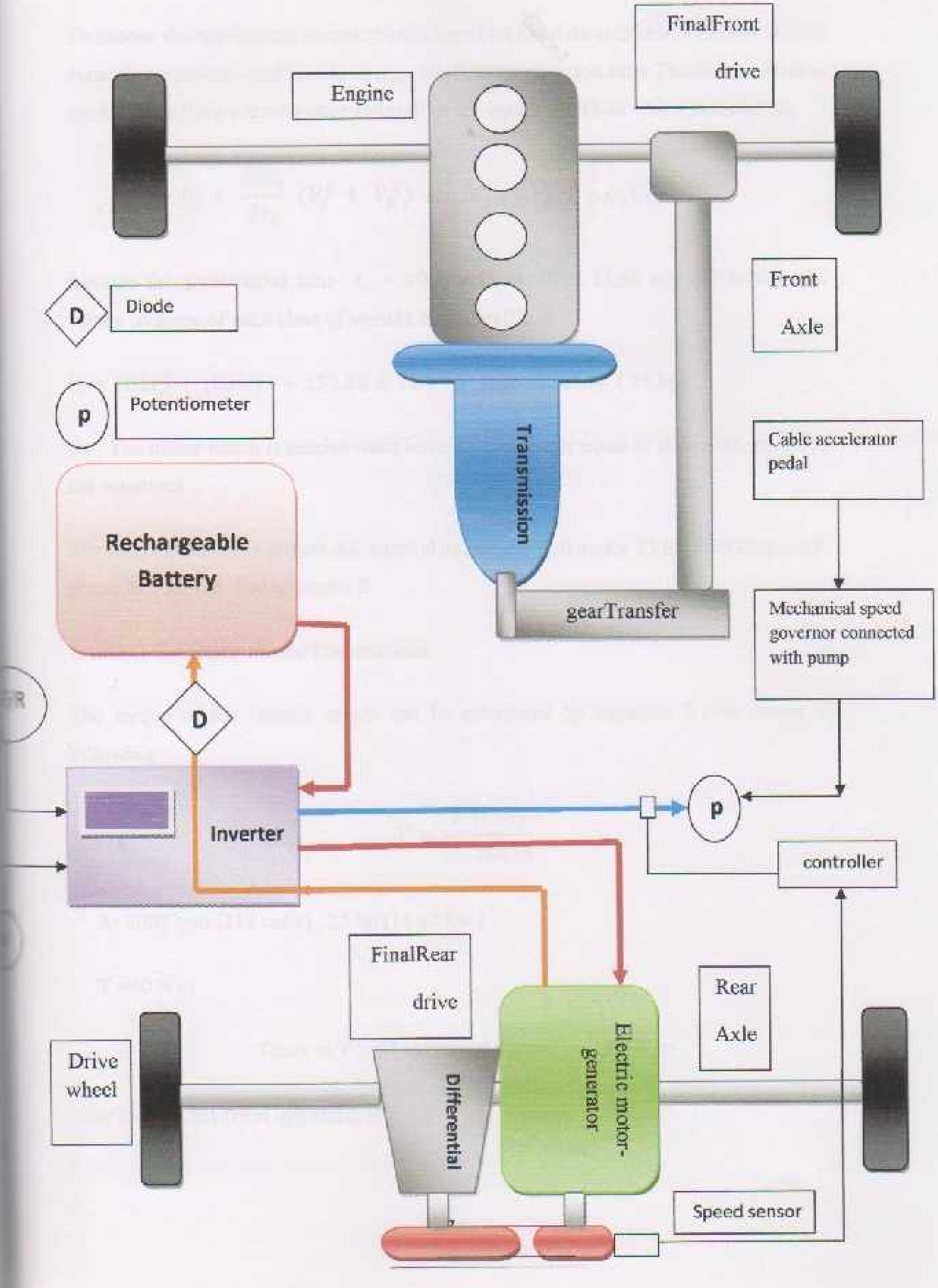


Figure 7.1: Mitsubishi L200 Double Cob 2000

7.2 Original Power Train Layout of Four Wheel Drive (4WD)



7.3 Power Train Layout of Parallel Hybrid Electric Vehicle



7.4 Electric Motor Calculation

7.4. 1Electric Motor Selection

To choose the appropriate electric motor based on the data available from the vehicle dynamic parameters and kinetic energy dividcto acceleration time.The motor which is needed must have a rated power as result of the equation5.18 as which is following

$$P_t = \frac{\delta M_v}{2t_a}(V_f^2 + V_b^2) + \frac{2}{3}M_v g f_r V_f + \frac{1}{5}\rho_a C_D A_f V_f^3$$

Assume the acceleration time $t_a = 10s$, velocity Vf = 13.88 m\s (50 km\h), this values average of such class of vehicle in city traffic.

P_t = 16125 + 1889.14 + 233.26 = 18.2 kw approximately (25 hp)

So , The motor which is needed must have a rated power equal or above the result of the equations.

The motor used in the project AC squirrel cage induction motor 25 hp, operating on 3-phase AC current. See appendix B

7.4.2AC Induction Motor Calculations

The torque of the electric motor can be calculated by equation 5.19as which is following

$$T = \frac{P\ (kw)}{\omega\ rad\backslash s}$$

At 3000 rpm (314 rad\s) , 25 hp (18.65 kw)

T =60 N.m

$$Tmax = T \times 3(\text{ over load factor}) = 180\ N.m$$

over load factor from appendix B

$$\omega \text{ critical} = \frac{P\ (kw)}{T\ (Nm)}$$

$$\omega \text{ critical} = 103.6 \text{ rad}\backslash s = 994.5 \text{ rpm}$$

ω critical is the last motor speed in (rpm) that the motor remains at highest torque.

To calculate the efficiency of the motor at 3000 rpm

$$\eta = \frac{Pout}{Pin} \times 100\% = \frac{V(volt) \times I_N(A)}{\omega(rad/s) \times T(N/m)} = \frac{400 \times 32.5}{314 \times 60} \times 100\%$$

$$= 69\%$$

I_N : form Appendix B .

2 pole AC motor operating on 50Hz power would have speed v controlled by inverter driver to increase or decrease power frequency . see appendix

$$V = \frac{120 \times f}{p} = \frac{120 \times 50}{2} = 3000\ rpm$$

V = motor speed (rpm) , f = AC power frequency (hertz) , p = Number of poles per phase

Figure 7.2 : Electric motor speed by variable frequency control

7.4. 3 Motor Vehicle Resistance

The rolling resistance calculated by equation 5.21 as which is following:

$F_{rr} = \mathcal{F}rr\ Mg = 0.013 \times 2000 \times 9.81 = 255\ N$

$\mathcal{F}rr = 0.013\ from\ appidix\ D$.

Climbing resistance calculated by equation 5.23 as which is following:

$F_{cr} = mg \sin(\varphi)$

If the grade 10 in 1the grade angle $\varphi = \sin^{-1}\frac{1}{10} = 5.7^{\circ}$ see Appendix

$$F_{cr} = 1948.6\ N.$$

And if grade 5 in 1 the grade angle$\varphi = \sin^{-1}\frac{1}{5} = 11.5$

$$F_{cr} = 3987.3\ N$$

The aerodynamic drag resistance is neglected because this resistance at low speed at small effect .

The total tractive effort resistance to grade 5 in 1from equation 5:26 as which is following:

$$F_{te} = F_{rr} + F_{cr} = 4242.3N$$

7.4.4 Single Gear Ratio Selection

The bottom gear ratio can be derived in the following:

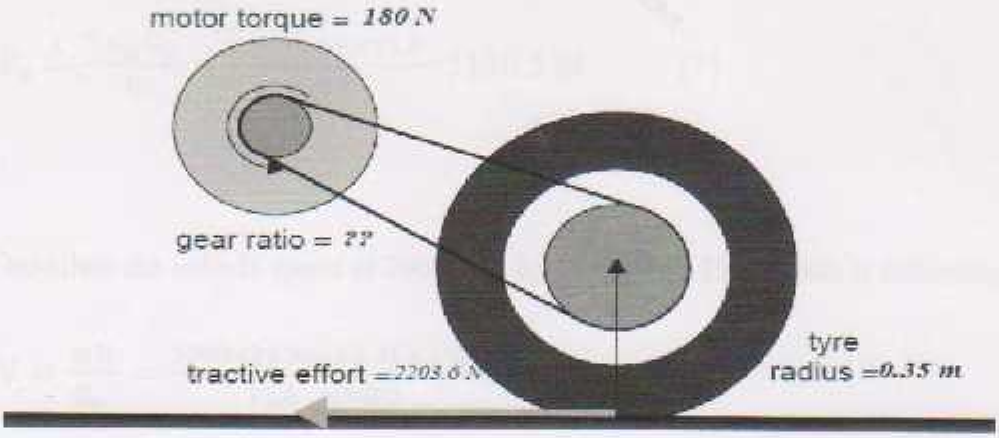


Figure 7.3 : Gear ratio for electrical motor

Driving torque = available torque

$$F_{te} \times R = T\, G_B\, G_F\, \mu_M$$

R=wheel radius (m)G_B = bottom gear ratio ,

G_F = final gear ratio μ_M =mechanical efficiency

$$G_B = \frac{F_{te} \times R}{T\, G_F\, \mu_M} = \frac{4242.3 \times 0.35}{180 \times 4.2 \times 0.86} = \frac{1484.8}{650.16} = 2.3 \approx 1{:}3$$

The maximum grade can the vehicle climb it can be derived in the following way

$$Fcr = \frac{T\, G_F\, G_B\, \mu_M}{R} - Frr = \frac{180 \times 12.6 \times .86}{0.35} = 5572.8\,N - 255 = 5317\,N$$

$\sin(\varphi) = Fcr \div mg = 15.4^{\circ}$ that mean the vehicle can climb gradient one in four

$$\text{gear ratio} = \frac{N2}{N1} = \frac{21}{58} \approx 1{:}2.76 \qquad [6]$$

N= number of teeth

The overall gear ratioat bottom gear $G_o = G_B\, G_F = 2.76 \times 4.2 = 1 : 11.6$.

To calculate the tractive forcewith grade 10 in 1 and overall gear ratio, from equation 5.23as which is following:

$$F_x = \frac{T \mu_M G_o}{R} = \frac{180 \times 0.86 \times 11.6}{0.35} = 5130.5 \text{ N} \qquad [7]$$

To calculate the vehicle speed at 3000 rpm by equation 5.25as which is following

$$V = \frac{\omega R}{G_o} = \frac{3000 \times 2\pi \times 60 \times 0.35 \times 0.98}{11.6 \quad \times 1000} = 33.4 \text{ km\textbackslash h}$$

Table 7.2 vehicle speed at various speed in flat road shown in table :

V rpm motor	V km\h Vehicle
1000	10.25733
2000	20.51467
3000	30.772
4000	41.02933
5000	51.28667

Table 7.3 The tractive effort by single gear electric part of vehicle and "rolling , climb" resistance as follow table .

V rpm	T N.m	w rad\s	Fx(N)	Go	P w	V km	F te N	F rr N
100	180	10.46667	5572.8	12.6	1884	1.025733	2203.6	255
200	180	20.93333	5572.8	12.6	3768	2.051467	2203.6	255
300	180	31.4	5572.8	12.6	5652	3.0772	2203.6	255
400	180	41.86667	5572.8	12.6	7536	4.102933	2203.6	255
500	180	52.33333	5572.8	12.6	9420	5.128667	2203.6	255
700	180	73.26667	5572.8	12.6	13188	7.180133	2203.6	255
800	180	83.73333	5572.8	12.6	15072	8.205867	2203.6	255
994.5	180	104.091	5572.8	12.6	18650	10.20092	2203.6	255
1300	137.0652	136.0667	4243.537	12.6	18650	13.33453	2203.6	255
1500	118.7898	157	3677.732	12.6	18650	15.386	2203.6	255
1700	104.8145	177.9333	3245.058	12.6	18650	17.43747	2203.6	255
2000	89.09236	209.3333	2758.299	12.6	18650	20.51467	2203.6	255

2300	77.47161	240.7333	2398.521	12.6	18650	23.59187	2203.6	255
2700	65.99434	282.6	2043.185	12.6	18650	27.6948	2203.6	255
3000	59.3949	314	1838.866	12.6	18650	30.772	2203.6	255
3300	53.99537	345.4	1671.697	12.6	18650	33.8492	2203.6	255
3700	48.15803	387.2667	1490.973	12.6	18650	37.95213	2203.6	255
4000	44.54618	418.6667	1379.15	12.6	18650	41.02933	2203.6	255
4300	41.43831	450.0667	1282.93	12.6	18650	44.10653	2203.6	255
4700	37.91164	491.9333	1173.744	12.6	18650	48.20947	2203.6	255
5000	35.63694	523.3333	1103.32	12.6	18650	51.28667	2203.6	255
6000	29.69745	628	919.4331	12.6	18650	61.544	2203.6	255

Figure 7.4 :AC induction motor power characteristics

Electric motors, however, usually have a speed–torque characteristic that ismuch closer to the ideal, as shown in Figure 7.4,5. Generally, the electric motorstarts from zero speed. As it increases to its base speed, the voltage increasesto its rated value while the flux remains constant. Beyond the base speed, thevoltage remains constant and the flux is weakened. This results in constantoutput power while the torque declines hyperbolically with speed. Since thespeed–torque profile of an electric motor is close to the ideal, a single-gear transmission is usually employed

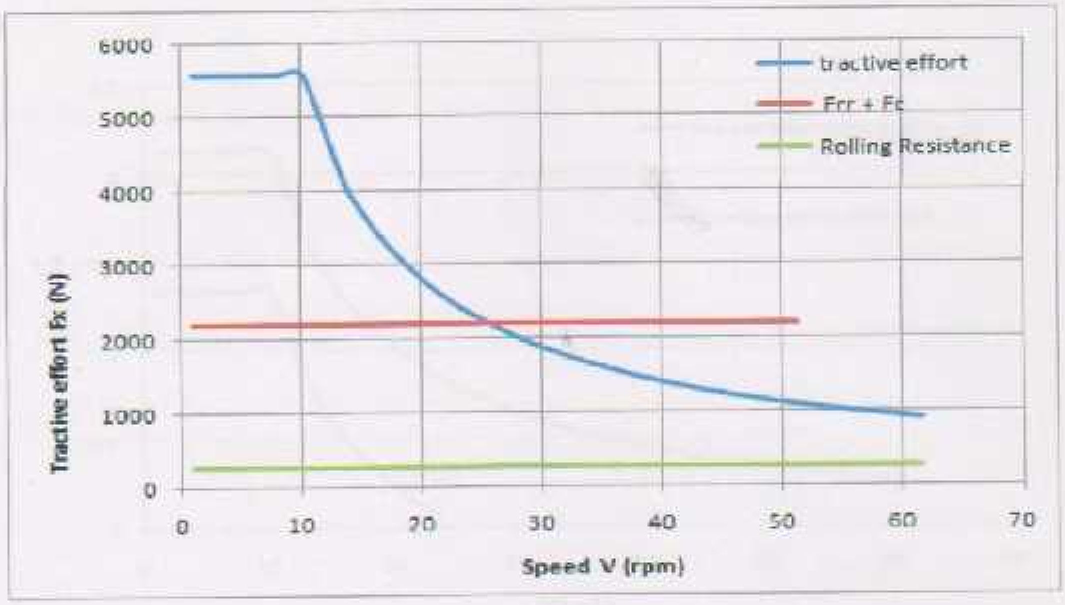


Figure 7.5 : Tractive effort of a single-gear electric vehicle vs. vehicle speed

The max speed for vehicle with electric motor at flat road at motor speed 4000rpm,60HZalmost to**40 km\h** with tarctive effort value in rolling resistance = 255 N(neglect of air resistance at low speed), and in grade 10 in 1 the max speed almost 25 **km\h** with total tractive effort value $Fte = Frr + Fcr(10\%) = 2203.6\ N$ (see the chart)

7 .4.5Acceleration Performance

The acceleration performance of a vehicle is usually described by its acceleration time and the distance covered from zero speed to a certain high speed Using Newton'ssecond law.

To calculate the acceleration of the vehicle at grade 10 in 1

$$a = \frac{F_x - F_{te}}{\delta M} = \frac{5572.8 - 2203.6}{1.25 \times 2000} = 1.4\ m/s^2 \qquad [8]$$

The acceleration at flat road without grade

$$a = \frac{F_x - F_{rr}}{\delta M} = \frac{5572.8 - 255}{2500} = 2.3\ m/s^2$$

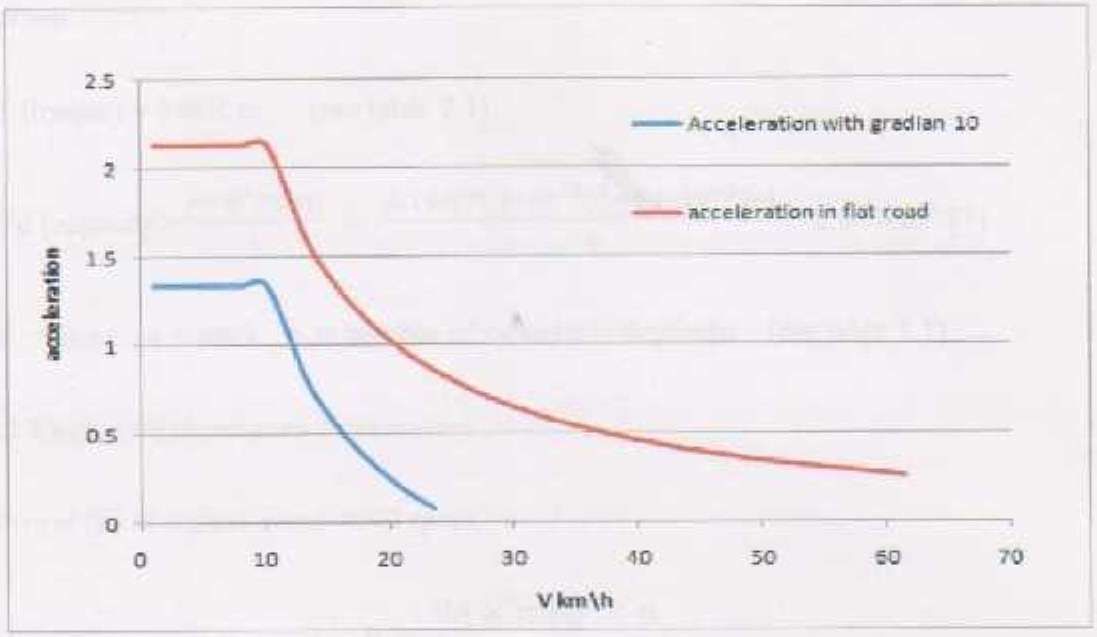


Figure 7.6: Acceleration of an electric machine-powered vehicle with single-gear transmission

The acceleration time at flat road to accelerate from 0 to 40 km/h [7]

$$t = \frac{V}{a} = \frac{40}{2.3} = 17s$$

7.5 Diesel Engine Calculations

7.5.1 The Mean Effective Pressure (mep)

The meaneffective pressure (mep)calculated by equation 4.2 as which is following:

$$Mep = \frac{\text{work per cylinder}}{\text{displacment of cylinder}} = \frac{2\,\pi\, n_R\, T\,(Nm)}{V_d} = \frac{2*3.14*2*240}{2.4777} = 1216.9 \text{ kpa}$$

Mep = (12.169 bar)

When:

T (torque) = 240N.m .. (see table 7.1)

Vd (capacity)= $\frac{\pi \times d^2 \times s \times n}{4} = \frac{3.14*(91.1*10^{-3})^2*(95*10^{-3})*4}{4}$ =2.477cm³ [7]

d = bore ., s = stork .,n = number of cylinder = 4cylinder . (see table 7.1)

7.5.2 Engine Performance Parameters

Power (P) at engine speed 4000 rpm :

$$P = \frac{Vd \times mep \times n}{600 \times k}$$

$$P = \frac{2.47 \times 12.169 \times 4000}{2 \times 600} = 100 \text{ kw (134 hp) [7]}$$

n = Engine speed , k = 2 for four stork engine

7.5.3Acceleration (acc) for Diesel Engine

Tractive force (F_x) at Torque (T=240) , $\omega = 4000$, $\eta = 86\%$.

$$F_x = \frac{T\, G_o \eta}{r}$$

Table 7.4 The tractive effort at various gear ratios in constant engine speed and constant torque based on above equation as follows:-

Gear Ratio		G= gear * Gf	T(N.m)	η (%)	r (m)	Fx	Gf
First gear	3.918	16.4556	240	0.86	0.35	9704.1	4.2
Second gear	2.261	9.4962	240	0.86	0.35	5600.04	4.2
Third gear	1.395	5.859	240	0.86	0.35	3455.14	4.2
Fourth gear	1	4.2	240	0.86	0.35	2476.8	4.2
Fifth gear	0.829	3.4818	240	0.86	0.35	2053.27	4.2

See appendix C for tractive effort at various speed

Velocity(V) at 4000 rpm:

$$V = \frac{\omega R}{G_o}$$

Table 7.5The velocity of the vehicle at gears ratiosand constant engine speed based on above equations as follows :

Gear Ratio		G= Gear* Gf	Ω	i(%)	r (m)	v m/s	Gf	VKm/h
First gear	3.918	16.4556	4000	0.02	0.35	8.72667	4.2	31.416
Second gear	2.261	9.4962	4000	0.02	0.35	15.1221	4.2	54.4396
Third gear	1.395	5.859	4000	0.02	0.35	24.5098	4.2	88.2351
Fourth gear	1	4.2	4000	0.02	0.35	34.1911	4.2	123.088
Fifth gear	0.829	3.4818	4000	0.02	0.35	41.2438	4.2	148.478

Rolling resistance (F_{rr}) calculated by equation 5.21as which is following:

$$F_{rr} = \mu\, Mg = 0.013 \times 2000 \times 9.81 = 255\ N$$

Climbing resistance calculated by equation 5.23 as which is following :-

$$F_{cr} = mg \sin(\varphi)$$

If the gradient 1 in 5 the gradient angle $\varphi = \sin^{-1}\frac{1}{5} = 11.53^{\circ}$,

$$F_{cr} = 3921.66\ N$$

If the gradient 1 in 10 the gradient angle $\varphi = \sin^{-1}\frac{1}{10} = 5.7$

$$F_{cr} = 1948.65\ N$$

If the gradient 1 in 15 the gradient angle $\varphi = \sin^{-1}\frac{1}{15} = 3.8^{\circ}$

$$F_{cr} = 1300\ N$$

Calculate aerodynamic drag force (F_{ad}) from equation 5:22as which is following :

$$F_{ad} = \frac{\rho\, C_D\, A_f V_r^2}{2}\, C_D \textit{ see appindix D}$$

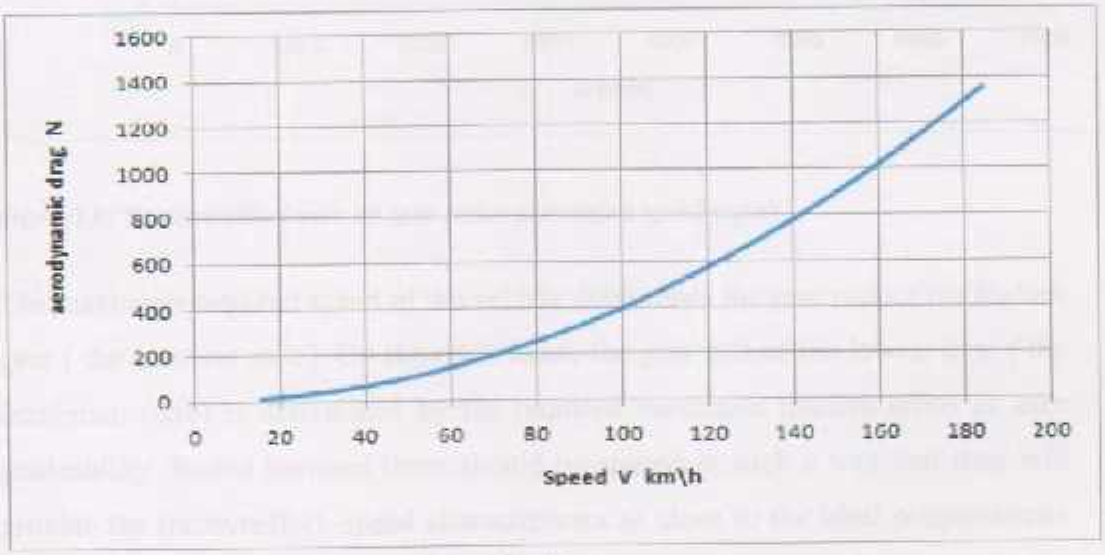


Figure7.7: Aerodynamic drag force VSspeedkm\h

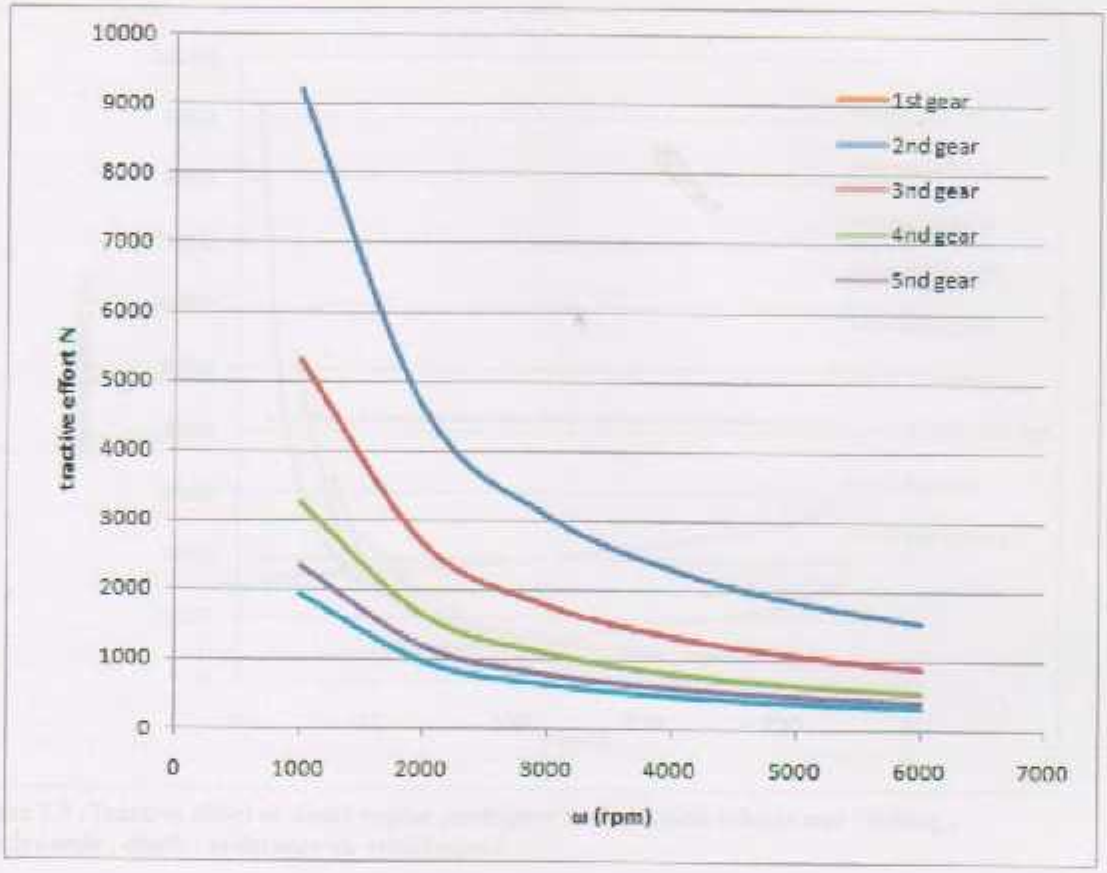


Figure7.8: Tractive effort over all gear ratios per engine speed (rpm)

The maximum required speed of the vehicle determines the gear ratioof the highest gear (the smallest ratio). On the other hand, the gear ratioof the lowest gear (the maximum ratio) is determined by the required maximum tractive effort or max gradeability. Ratios between them should be spaced in such a way that they will provide the tractiveeffort–speed characteristics as close to the ideal progressionas possible, as shown in figure 7.6. In the first iteration, gear ratios between the highest and the lowest gear may be selected in such a way that the engine can operate in thesame speed range for all the gears.

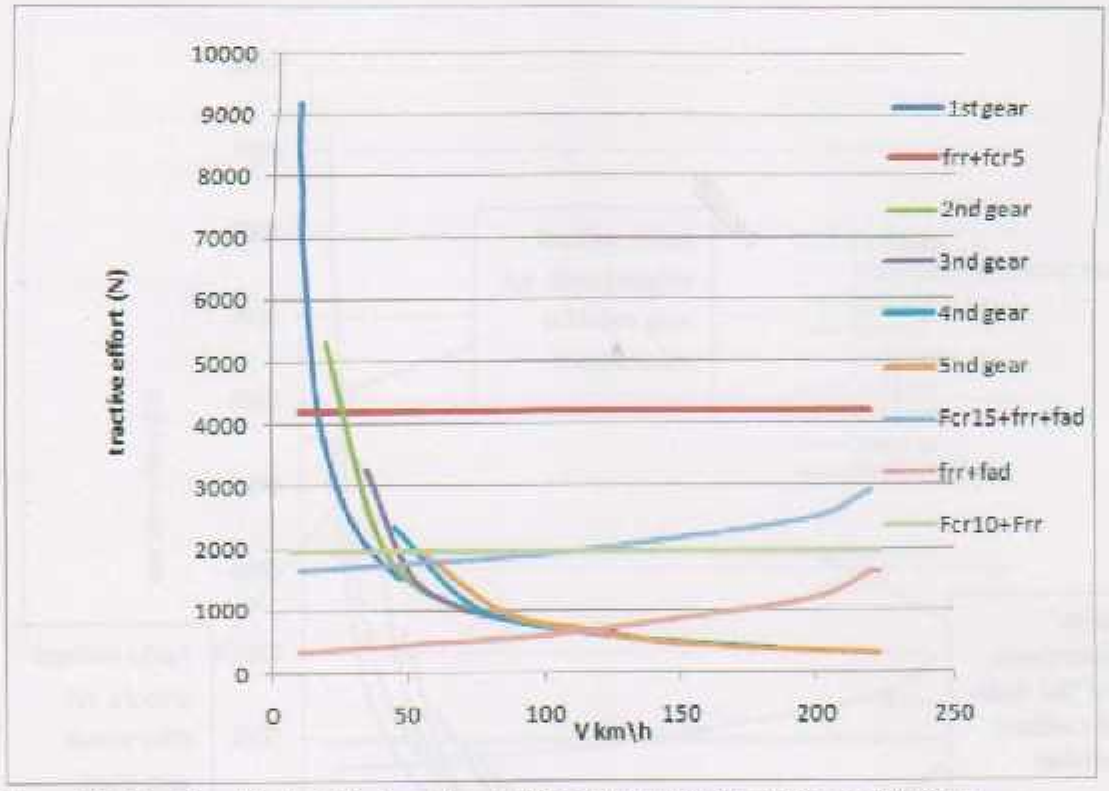


Figure 7.9 :Tractive effort of diesel engine ,multigear transmission vehicle and "rolling , aerodynamic , climb" resistance vs. vehiclespeed

If the vehicle in flat road with resistance force are rolling resistance and aerodynamic drag force .

$Fte = Frr + Fad\ at$ 120 =593.7 N

Then the max speed of the vehicle at value of tractive effort will be 120 km\h.

The speed of the vehicle could reach more than **120 km\h** if the driving cycle on down hill (negative gradient) .

If the vehicle in grade 5 in 1 with resistance force are rolling resistance and grade resistance .

$Fte = Frr + Fcr5$ =4176.66 N

Then the max speed of the vehicle at value of tractive effort will be **35 km\h**

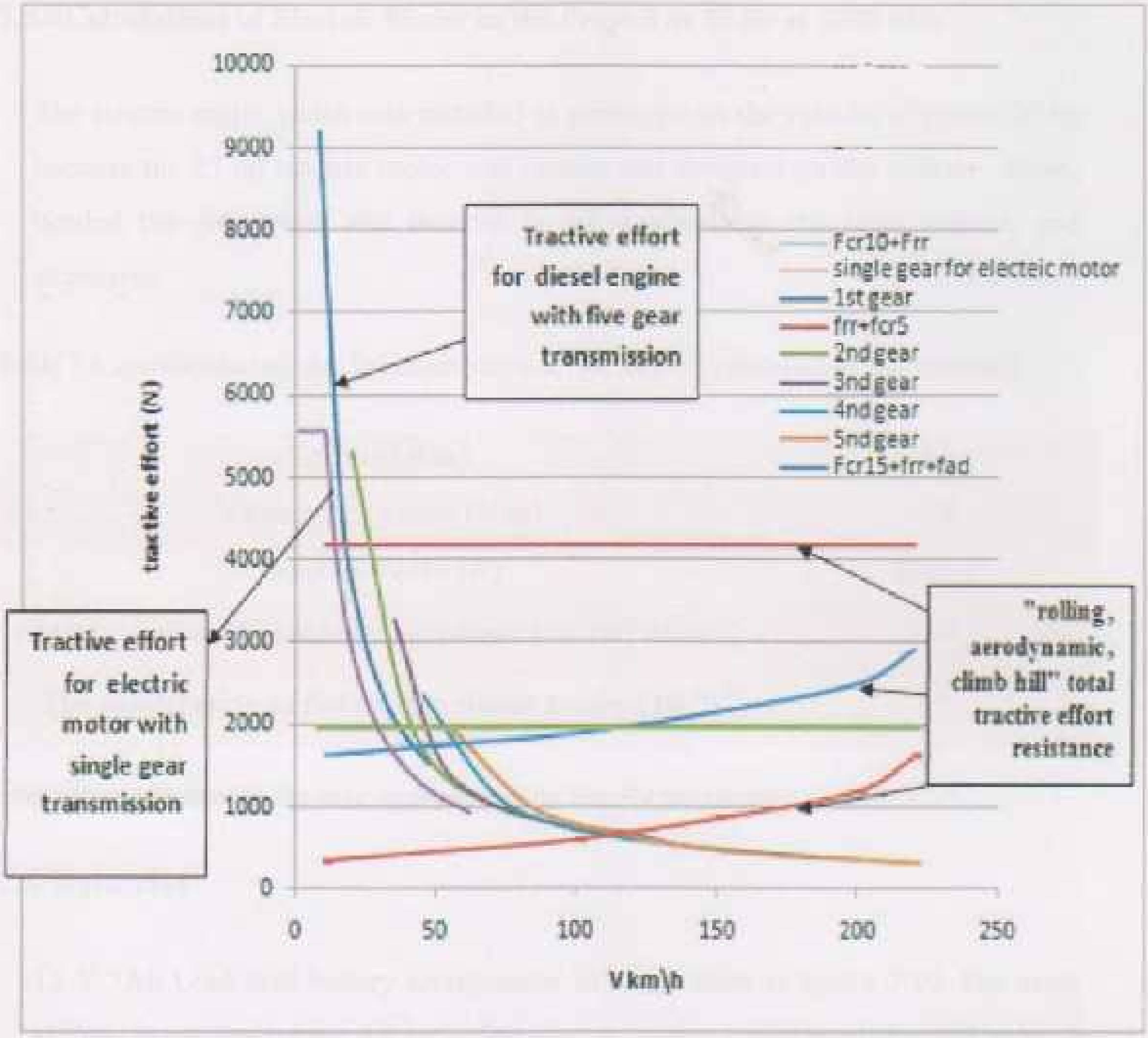


Figure 7.10: Tractive efforts of a diesel engine vehicle with five-gear transmission and an electric vehicle with single-gear transmission (more data for charts see Appendix)

Figure 7.10 shows the tractive effort of a diesel engine vehicle with five-gear transmission and that of an electric vehicle with single-gear transmission.It is clear that electric machines with favorable torque speed characteristics can satisfy tractive effort with simple single-gear.

7.5.4Calculations of Electric Motor in the Project as 20 hp at 3000 rpm

The electric motor which was installed as prototype on the vehicle, at power 20 hp because the 25 hp electric motor was chosen and designed on the vehicle above, needed the AC driver and inverter is not available in the local market, and expensive.

Table 7.6 specification of AC Induction motor 20 HP (15 kw) installed on the vehicle(1)

Torque (N.m)	49
Maximum Torque (N.m)	128
Tractive Force (N)	3916.8
Acceleration of the vehicle at gradient 1 in 10 (m/s^2)	0.68
The acceleration at flat road without grade (m/s^2)	1.4

1)this values calculated by the same equation which the 25hp EM was calculated .

7.6 Batteries

12 V 7Ah Lead acid battery arrangement in series form as figure 7.10, For more voltage to run the 3phase AC induction electric motor, which needs for 380 volts to operate and to overcome the voltage lost in inverter during the process of filtering the DC to AC ,the Vdc need to operated 530 DC that mean 44 battery and 570 DC at fully charged , if no charge presses, and the electric motor operated at max load in 27 A. the battery can operate before empty by equation 4.6

$$t = \frac{C}{I} = \frac{7}{27} = 16\ min, I:\ \text{from appendix B .}$$

$$Vdc = \sqrt{2} \times 380\ AC\ = 532\ DC\ volt\ needed\ to\ run\ inverter$$

This means that number of batteries is $\frac{532}{12} - 44$ lead acid batteries

At fully charged $13 \times 44 = 575\ DC$

Figure 7.11:Lead acid battery 12V and 7Ah

Figure 7.12: Lead acid batteries connected in series

7.7 Operating Modes and Control Strategy

The drive train has several operating modes, depending on the operation and conditions of the engine and electric motor.

7.7.1 Engine-alone Traction Mode and Hybrid Charging Mode.

In this mode, the electric motor is shut down,and the vehicle is propelled by the diesel engine alone. This mode may be usedwhen the state-of-charge (SOC) of the batteries,at speed over 50km/h or when butteries need recharged and the engine alone can handle the power demand, in this mode, the AC induction electric motor operates as a generator driven by the engine to charge the batteries, it generate AC current converted to DC by inverter and stored in batteries.

7.7.2Motor-alone Traction Mode and Regenerative Braking Mode .

In this mode, the engine is shut down or set idling and the clutch is disengage(Neutral) vehicle is propelled by the electric motor alone. This operating mode used at low vehicle speed. and in this mode the electric motor is operated to produce a braking torque to the drive train. Part of the kinetic energy of the vehicle mass is converted into electric energy at AC current and convert by inverter to DC and stored in the batteries.

7.7.3 Inverter with Variable Frequency Controller

The inverter work to convert DC current from batteries to AC current to drive the AC induction motor and also convert AC to DC to charge the battery by regenerative braking ,the inverter also work as frequency converter it control to the speed of the electric motor by potentiometer pedal, and it consist the controller able to programming from the user, such as controlling the speed ,acceleration , desecration, over load voltage, potentiometer pedal calibration, reveres forward switch ,and hand brake switch.

Figure 7:13 delta variable frequency converter type VFD-F 15 KW

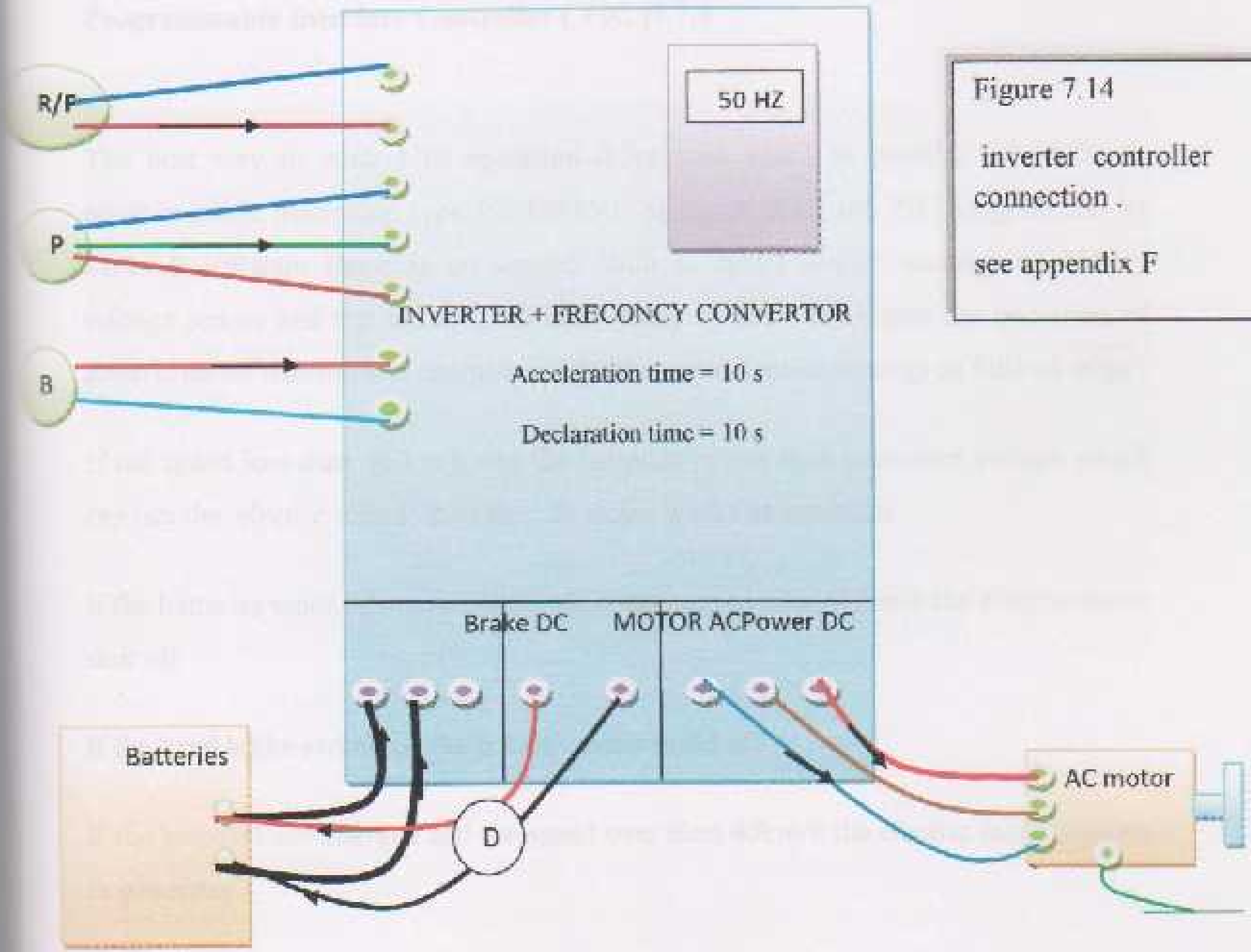


Figure 7.14

inverter controller connection .

see appendix F

R Reveres , Forward switch, P potentiometer pedal D diode, B Brake

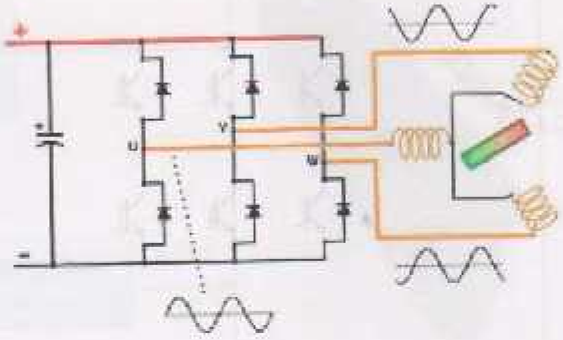


Figure 7.15: 3 Phases inverter internal circuit

Programmable Interface Controller (PIC)7.7.4

The best way to control to operation drive train mode in parallel hybrid byuse programmable microchip type PIC18F550 as figure 7.12, the PIC programmed by MPLAP software Depends on sensors such as speed sensor reading and battery voltage sensor and the signal from hand brake switch , to control the operation of electric motor traction and charging mode. the control mode strategy as follows steps

If the speed less than 40 km/h and the batteries is less than minimum voltage which can run the electric motor then electric motor works as generator

If the batteries more than minimum voltage and speed over 40 km/h the electric motor shut off

If the hand brake switch on the potentiometer pedal off .

If the batteries not charged and the speed over than 40km/h the electric motor operate as generator.

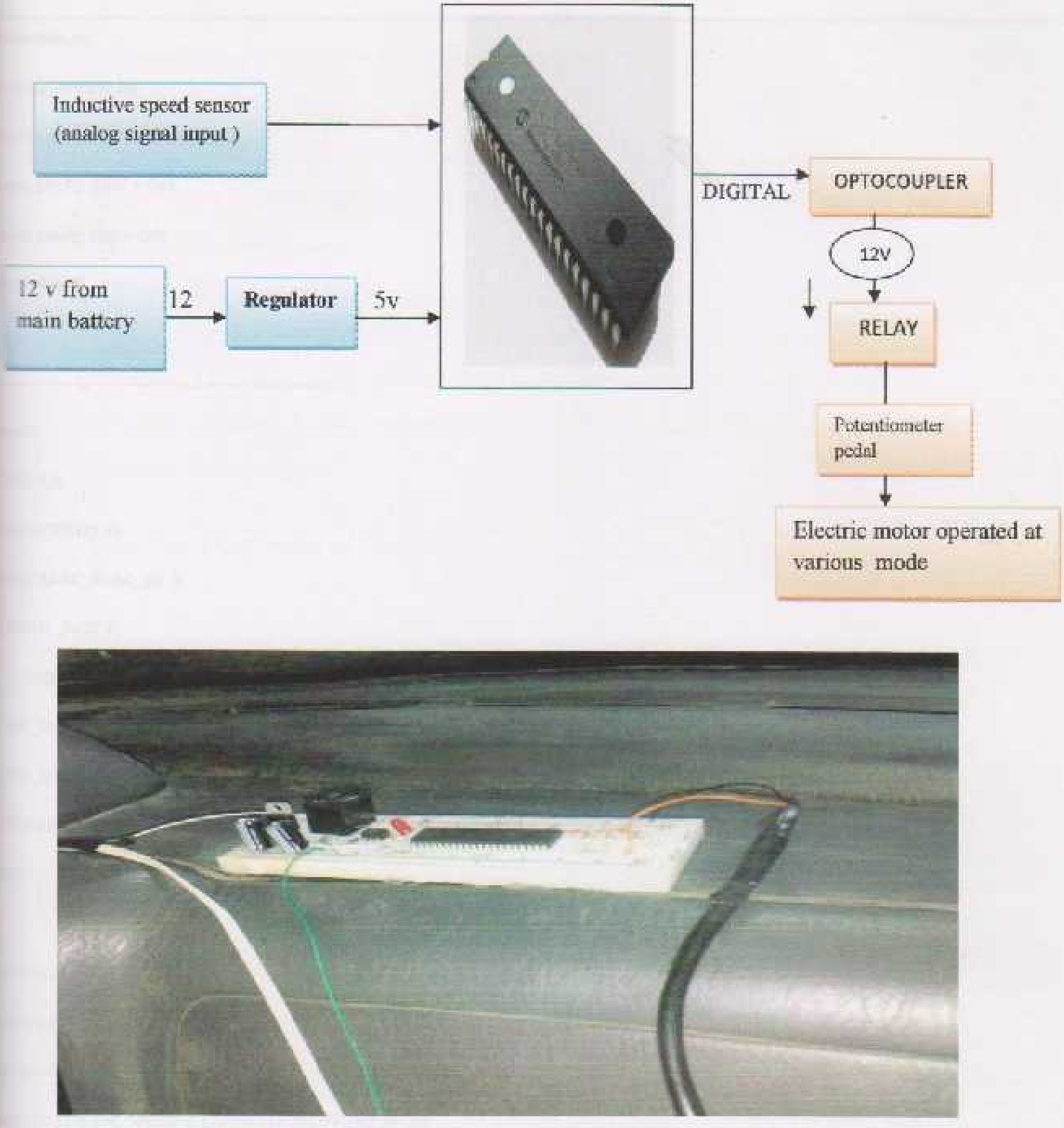


Figure 7.16: PIC 18F4550 block diagram and controller board

Pic needed to feed it 5v , the battery voltage 12v must regulate it to 5v needed to operate pic ,the signal from sensor such as analog input to the programmed controller and output digital signal ,optocoupler used to protect controller ,the relay operated at 12 v to control to potentiometer pedal to drive the electric motor at various operation mod.

```
lude<adc.h>

lude<p18f4550.h>

agma config FOSC = INTOSC_HS

agma config WDT = OFF

agma config LVP = OFF

d main(void)

---------------------------

result;

CON1=13;

Dbits.TRISD3=0;

enADC (ADC_FOSC_64 &

C_RIGHT_JUST &

C_2_TAD,ADC_CH1 &

C_INT_OFF &

C_REF_VDD_VSS , ADC_2ANA);

TDbits.RD3=1;// TURN THE RELAY ON

ile(1)

vertADC();

ile(BusyADC());

ult=ReadADC();

>60)//IF THE SPEED IS LARGE TURN OFF THE RELAY

TDbits.RD3=0;

result<50)//IF THE SPEED BECOMES SLOW TURN THE RELAY ON

TDbits.RD3=1;
```

Figure 7.17: pic code programming by MPLAP software

7.8 Design and Analysis for Mechanical Part:

This part of the project shows, explanation the mechanical parts used in the project, Clarify the design method, and the parts connection by welding and bolts, by using CATIA programming :

A. drawpart

B. Work simulation of the parts on the program through the selected types of materials used and choice the materials used for assembled(welding and bolts).

C . Analysis of the forces and mechanical parts to illustrate the results by report from the same program.

7.8.1 The Final Form of the Design:

After drawing mechanical parts, each one alone, to identify the dimensions, identify materials used, chose the appropriate type of welding and type the appropriate screws, pieces have been grouped together, the figure 7.18 shown final form for electric motor chassis.

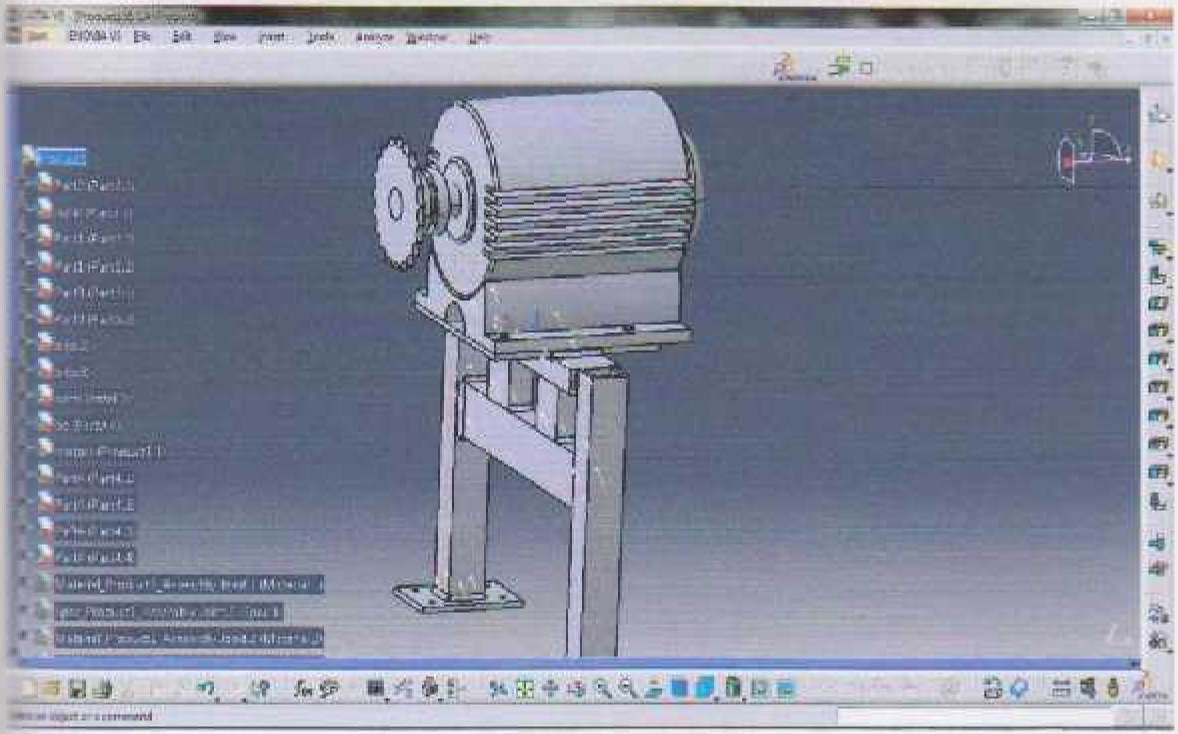


Figure 7.18 : Electric Motor and chassis

7.8.2 Bolt Mechanical Design

To design 4 bolt type iso 8.8 ,12mm can be derived in the following way

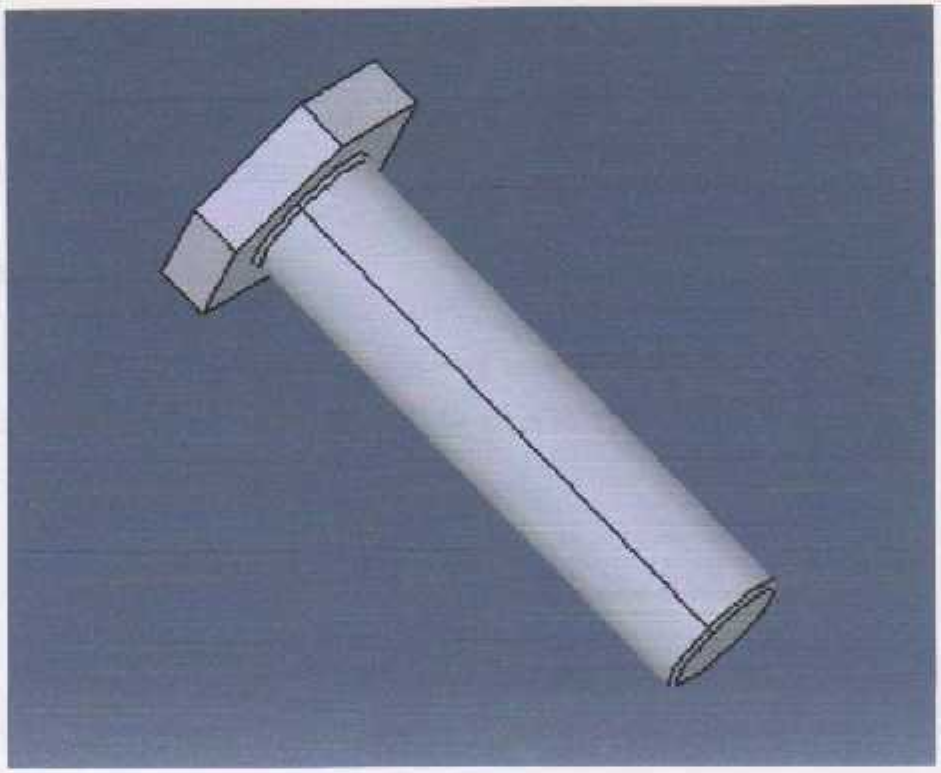


Figure 7.19: Bolt diagram

The external tensile load per bolt (P) :

$P = F_{torque} + F_{load}$

P = 900*9.81+5*9.81+10*9.81+(180) =1210 N= 1.21 Kn

Assuming reused connection

$$F_i = 90F_pF_p = s_pA_t$$

F_i: preload F_p: resultant bolt load

$A_t = 84.3 * 10^{-6}$: see appendix E

$S_p = 600\ mpa$: see appendix E

$F_p = 600 * 10^6 * 84.3 * 10^{-6} = 50.58*10^3$

$F_i = 90 * 50.58*10^3 - 45.52*10^3$

$n = \frac{S_p A_t - F_i}{P} = \frac{50.58*10^3 - 45.52*10^3}{1.21} - 4.1 > 1 \Longrightarrow$ **safe .**

This bolt used to fix the electric motor and other 8 bolt to fix the chassis at axle.

7.9 Analysis and Results:

By using CATIA we got the following results, pictures, and tables shown the mechanical analysis of the chassis under all applied forces affecting it.

Analysis1

MESH:

Entity	Size
Nodes	233911
Elements	985889

ELEMENT TYPE:

Connectivity	Statistics
TE4	985889 (100.00%)

ELEMENT QUALITY:

Criterion	Good	Poor	Bad	Worst	Average
Distortion (deg)	938805 (95.22%)	46388 (4.71%)	696 (0.07%)	57.570	22.762
Stretch	985881 (100.00%)	8 (0.00%)	0 (0.00%)	0.285	0.693
Length Ratio	985851 (100.00%)	38 (0.00%)	0 (0.00%)	5.612	1.710

Materials.1

Material	Iron
Young's modulus	1.2e+011N_m2
Poisson's ratio	0.291
Density	7870kg_m3
Coefficient of thermal expansion	1.21e-005_Kdeg
Yield strength	3.1e+008N_m2

Static Case

Boundary Conditions

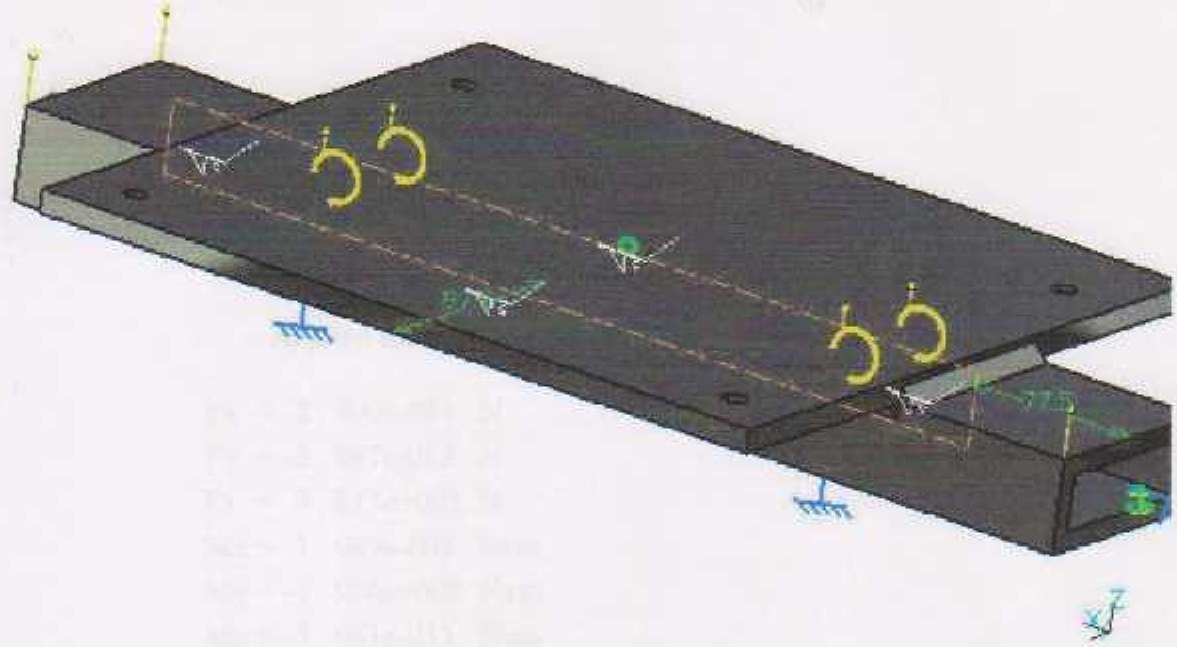


Figure 1

STRUCTURE Computation

Number of nodes	: 233911
Number of elements	: 985889
Number of D.O.F.	: 701733
Number of Contact relations	: 0
Number of Kinematic relations	: 0

Linear tetrahedron : 985889

RESTRAINT Computation

Name: RestraintSet.1

Number of S.P.C : 107982

LOAD Computation

Name: Loads.1

Applied load resultant :

Fx = 2 . 490e-013 N
Fy = -2 . 087e-012 N
Fz = 9 . 013e+002 N
Mx = 1 . 989e-008 Nxm
My = -3 . 986e+002 Nxm
Mz = -5 . 061e-013 Nxm

STIFFNESS Computation

Number of lines	:	701733
Number of coefficients	:	13343469
Number of blocks	:	27
Maximum number of coefficients per bloc	:	500000
Total matrix size	:	155 . 38 Mb

SINGULARITY Computation

Restraint: RestraintSet.1

Number of local singularities	:	0
Number of singularities in translation	:	0
Number of singularities in rotation	:	0
Generated constraint type	:	MPC

CONSTRAINT Computation

Restraint: RestraintSet.1

Number of constraints	:	107982
Number of coefficients	:	0
Number of factorized constraints	:	107982
Number of coefficients	:	0
Number of deferred constraints	:	0

FACTORIZED Computation

Method	:	SPARSE
Number of factorized degrees	:	593751
Number of supernodes	:	12030
Number of overhead indices	:	2055273
Number of coefficients	:	232334094
Maximum front width	:	4248
Maximum front size	:	9024876
Size of the factorized matrix (Mb)	:	1772 . 57
Number of blocks	:	117
Number of Mflops for factorization	:	2 . 751e+005
Number of Mflops for solve	:	9 . 323e+002
Minimum relative pivot	:	4 . 306e-002

DIRECT METHOD Computation

Name: StaticSet.1

Restraint: RestraintSet.1

Load: LoadSet.1

Strain Energy : 2.352e-004 J

Equilibrium

Components	Applied Forces	Reactions	Residual	Relative Magnitude Error
Fx (N)	2.4898e-013	2.2184e-012	2.4673e-012	3.6851e-013
Fy (N)	-2.0873e-012	-4.4270e-012	-6.5143e-012	9.7295e-013
Fz (N)	9.0130e+002	-9.0130e+002	5.3774e-011	8.0314e-012
Mx (Nxm)	1.9887e-008	-1.9887e-008	2.5579e-013	7.8770e-014
My (Nxm)	-3.9857e+002	3.9857e+002	-2.1771e-011	6.7043e-012
Mz (Nxm)	-5.0614e-013	-2.4626e-012	-2.9687e-012	9.1421e-013

Static Case Solution.1 - Deformed mesh.2

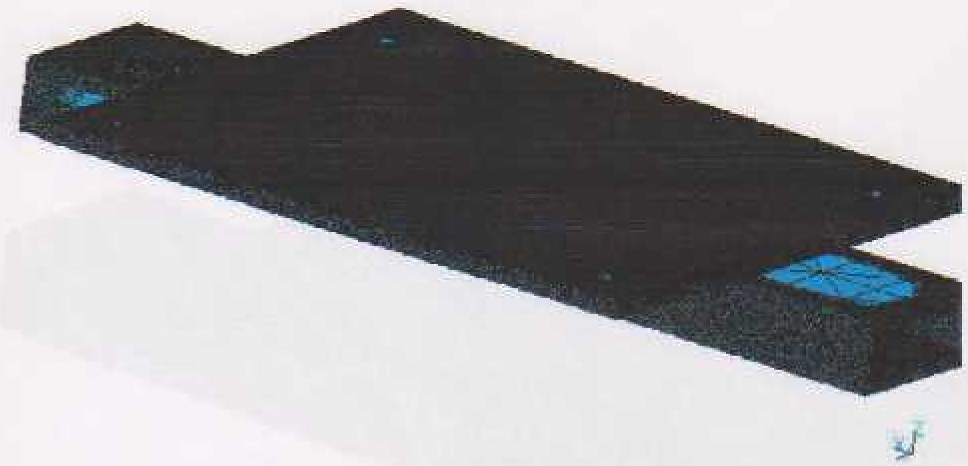


Figure 2 On deformed mesh ---- On boundary ---- Over all the model

Static Case Solution.1 - Von Misesstress (nodal values).1

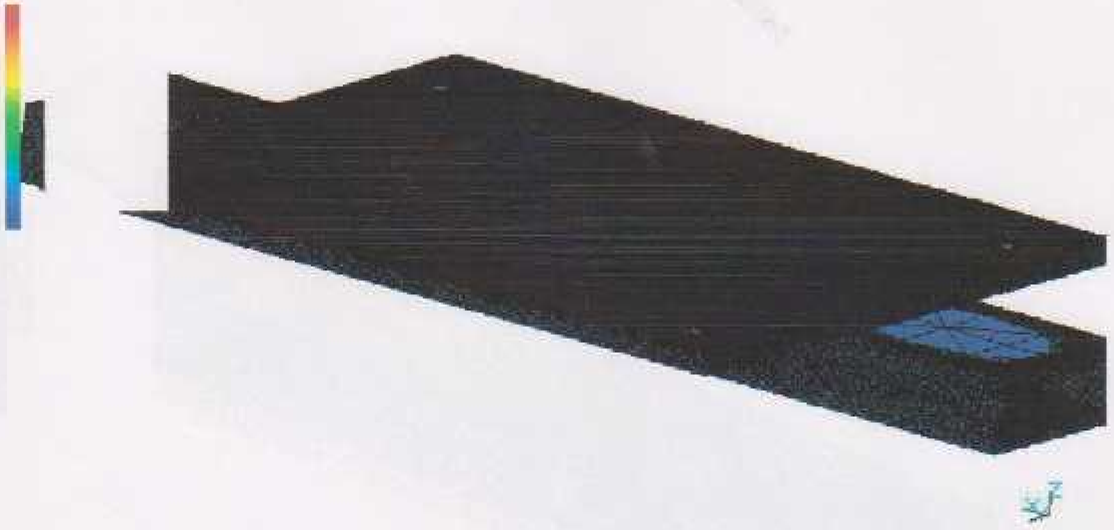


Figure 3 :3D elements: : Components: : All

On deformed mesh ---- On boundary ---- Over all the model

Static Case Solution.1 – Deformedmesh.1

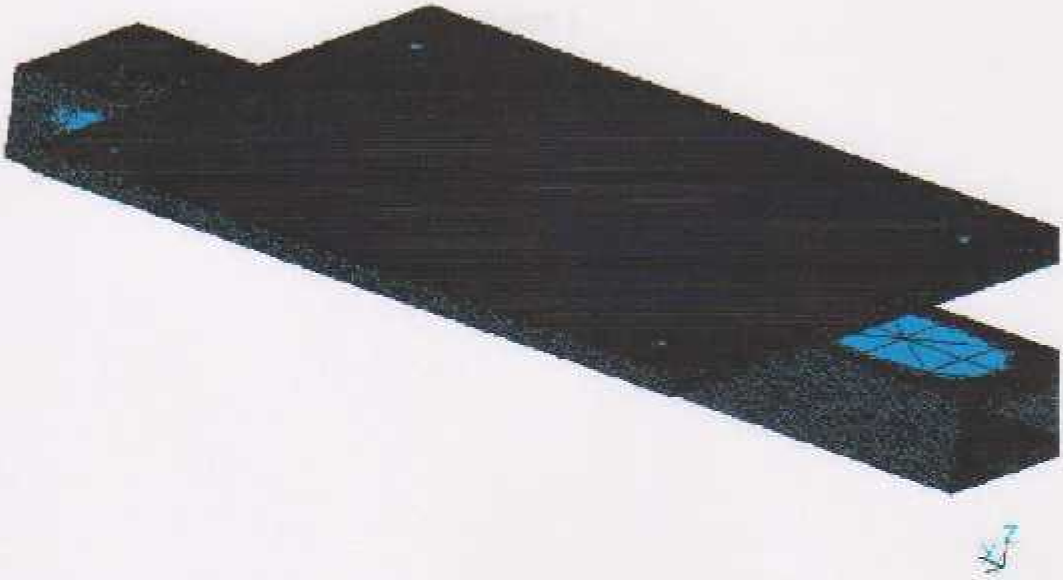


Figure 4 :On deformed mesh ---- On boundary ---- Over all the model

Static Case Solution.1 - Translational displacement vector.1

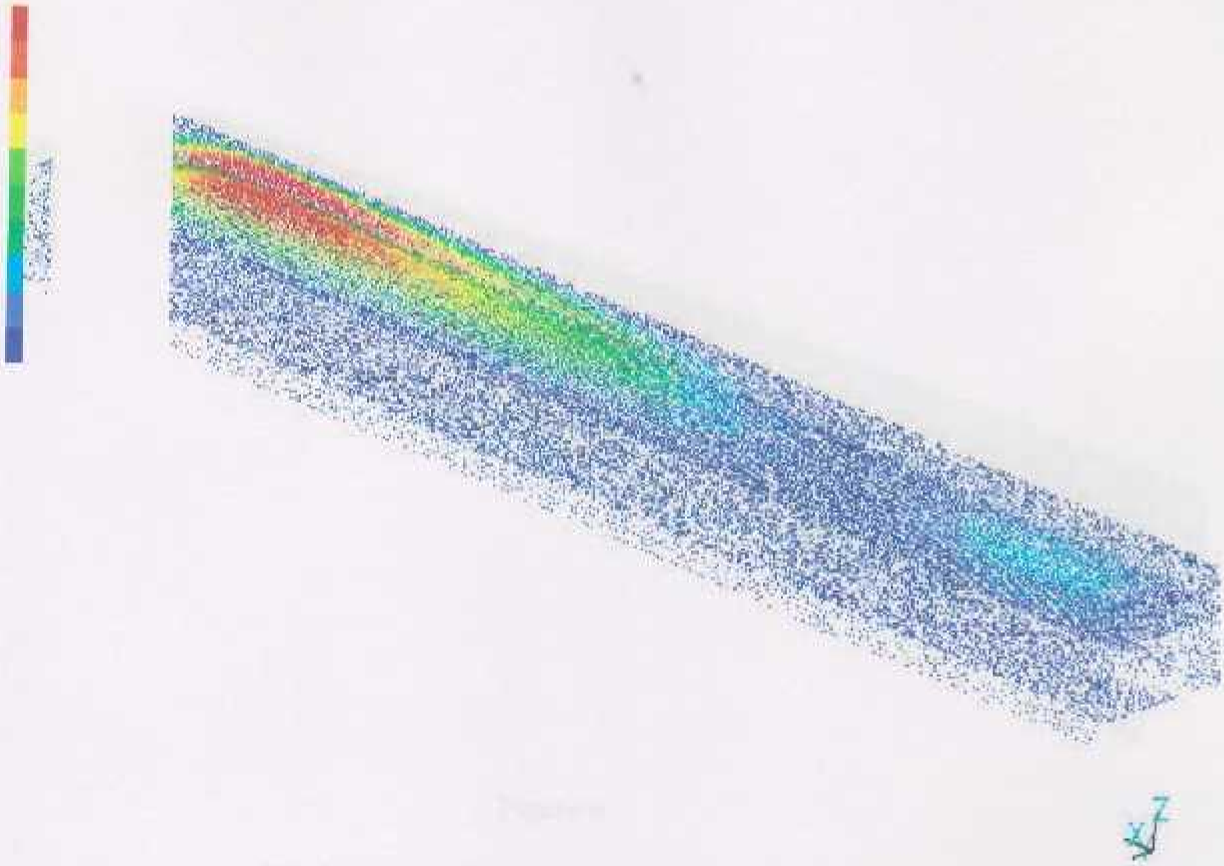


Figure 5

3D elements: : Components: : All

On deformed mesh ---- On boundary ---- Over all the model

Static Case Solution.1 - Stress principal tensor symbol.1

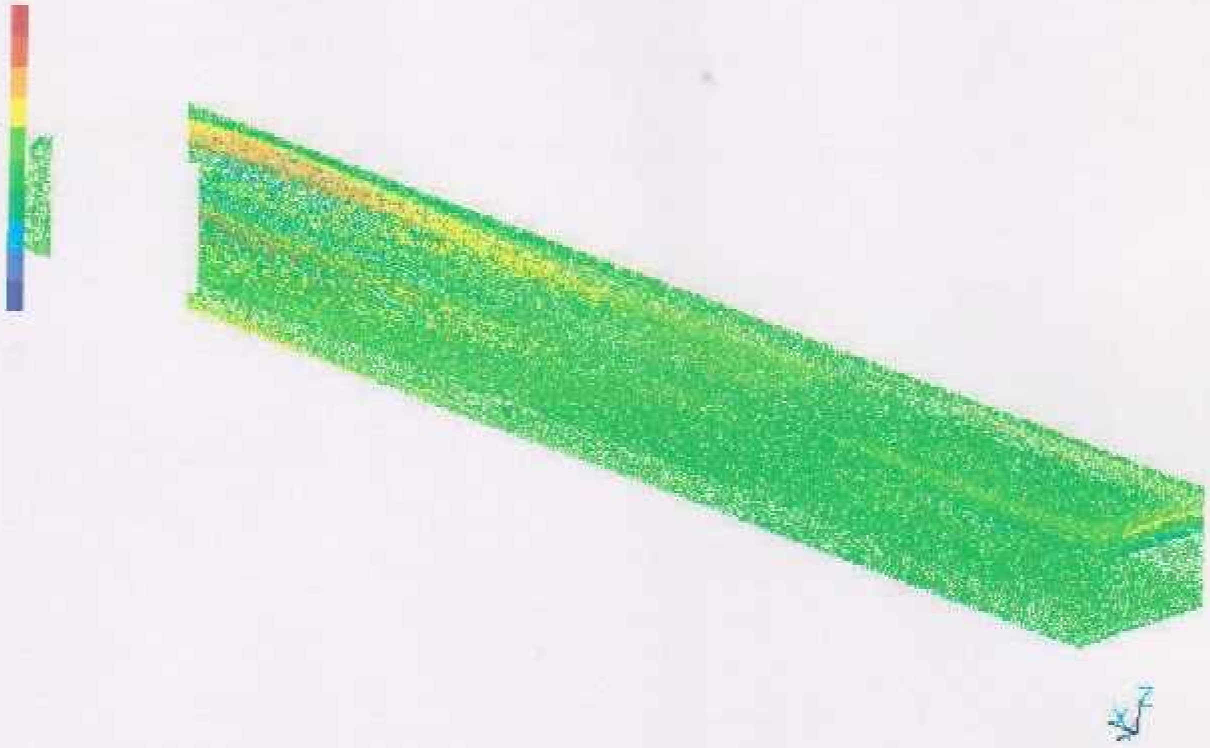


Figure 6

3D elements: : Components: : All

On deformed mesh ---- On boundary ---- Over all the model

Global Sensors

Sensor Name	Sensor Value
Energy	2.352e-004J

After seeing the analysis resultson the CATIA report, the system which was designed is safety, and to strengthen the weak points in thechassis which designed (red dots in the figure) used shock absorber and springs as shown in figure 7.28,27.

7.10 Project Building

After calculations the suitable EM was selected which power is 25 hp but the available in local market 20 hp and this was used in the system in addition to other components as inverter, batteries, pedal, gears, chain, and cables.

Then installing the components step by step as following:

Step 1: electrical motor installing, by putting it on the rear axle after building a chassisfor it on rear and fixed it.

Figure7.20: Building EM chassis fixed on rear axle

In figure 7.20 the area between the two axles is not enough comparing with EM size, because of the exhaust pipe and the fuel tank, so rear final drive must rotate and reverse it's direction 180 degree to give enough area as shown in figure 7.20.

Figure7.21: Howreversed final drive

Step 2 : putting gear with 30 cm diameter connected with differential and another gear connected with EM with 10 cm diameter ,this two gears connected by chain to give 1:3 gear reduction to increase torque and differential gives 1:4.2 gear ratio , and total out put is 1:11.6as shown in figure:7.22

Figure7.22:Gears connectionsand how EM carried on rear axle

Step 3: Installing the inverter with EM and batteries box to invert the DC current of batteries to AC current to run EM and vice versa while charging batteries, then inverter works as frequency converter.

Figure7.23: EM 's connection with gear by chain

Figure7.24 :Wiring connections between EM and inverter

Step 4: Making wiring connections and connect a pedal controls the EM speed , which has potentiometer connected with mechanical speed governor at diesel pump to control the variable frequency which drives the EM depending on road conditions and speed required, cable accelerator pedal and speed governor design to make rotary movement, this movement was calibrated with the potentiometer by mechanism to make same pedal to the electric motor and diesel engine, and then calibrate the potentiometer with inverter to give a direct proportion always, such as increasing load on pedal gives more frequency and more speed and vice versa as shown in figure 7.26.

Figure 7.25 : Mechanical speed governor with potentiometer

Step 5: Put a reverse forward switch on dash to make it easier for the driver when return back this button connected with inverter which can do this process by it's programming .

Step 6 : inductive speed sensor connected with the EM gear to give information about speed to the controller as shown in figure 7.26.

Figure7.26:Inductive speed sensor and teeth connected with gear in electric motor

Step 7: to overcome vibrations caused by electric motor at starting and stopping, because the driveshaft connected with the rear final drive are removed , the rear final drive still free, and to strengthen the motor chassis, shock absorbers and springs were put, and inverter was programmed to avoid vibrations at acceleration and deceleration as shown in figure 7.27,28.

Figure 7.27: Shock absorber

Figurer 7.28: spring and shock absorber

Figure 7.29: Final form to project

7.11 Conclusions and recommendations .

1. Choosing Light weight vehicle for hybrid applications.

2. The electric motor for this project must be at least 25 hp to give sufficient acceleration.

3. Choosing inverter which able to drive AC motor at different road conditions and has protection circuit to avoid over load damaging.

4. Develop the control system to increases the efficiency of regenerative braking, at different operating conditions to regulate the movement between ICE and AC motor.

5. Take advantage of the thermal energy, resulting from the mechanical brakes, and convert it into electrical energy to charge batteries.

6. To work on a follow-up development at the batteries technology, to use batteries to store energy for long time.

7. Design mechanical coupling device to connect the IC engine and electric motor to propelled the vehicle at the same time at hybrid mode.

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Appendix

Appendix A

Mitsubishi L200 Triton Double Cab 4x4 Specifications

Specifications			2.5 Double cab GLS	2.5 Double cab GLS-Limited (A/T)	3.2 Double cab GLS-Limited (M/T)	3.2 Double cab GLS-Limited (A/T)
Dimension & Weight	Length	(mm.)	5185	5070		
	Width	(mm.)	1800			
	Height	(mm.)	1780			
	Wheelbase	(mm.)	3,000			
	Front track	(mm.)	1520			
	Rear track	(mm.)	1515			
	Bed interior length	(mm.)	1325			
	Bed interior width	(mm.)	1,470			
	Bed interior height	(mm.)	405			
	Ground clearance	(mm.)	205			

	Approximate Vehicle Kerb weight	(Kg)	1875	1895	1945	1955
Engine	Model		4D56 DI-D Hyper Common Rail Turbo Intercooler		4M41 DI-D Hyper Common Rail Turbo Intercooler	
	Type		4 สูบ DOHC 16 วาล์ว			
	Displacement	(cc)	2,477		3,200	
	Bore x stroke	(mm.)	91.1 X 95.0		98.5 X 105.0	
	Compression ratio		17.0 : 1			
	ECE Net (Max.output-ECE Net)	(Kw) (PS) / (rmpm)	103(140)/4000		121(165)/4000	
	ECE Net (Max.torque-ECE Net)	(rmp)	321/2000		351/2000	
	Type		Electrical fuel injection (Common rail)			
(Fuel system)	Fuel tank capacity	litre	75			
	Clutch		(Mechanical)	(Torque converter)	(Mechanical)	(Torque converter)
(Transmission)	Type		Manual 5speed	(Auto 4speed)	Manual 5speed	(Auto 4speed)
	Model		5M/T	4A/T	5M/T	4A/T

			(V5MB1)	(V4A5A)	(V5MB1)	(V4A5A)
	Gear Ratio	1st	4.313	2.842	4.313	2.842
		2nd	2.33	1.495	2.33	1.495
		3rd	1.436	1	1.436	1
		4th	1	0.731	1	0.731
		5th	0.789	-	0.789	-
		ถอยหลัง (reverse)	4.22	2.72	4.22	2.72
	Transfer gear ratio	High	1			
		Low	1.9			
	Final gear ratio		4.1			
(Steering)	Type		Rack and pinion with power steering			
	Min. turning radius	(m)	5.9			
(Suspension)	Front		Independent-wishbone, coil springs with stabilizer bar			
	Rear		Regid-elliptic leaf springs			
Brake	Front		Ventilated discs			
	Rear		Leading and trailing drums			
(Tyres size)	Front & rear		245/70R16			

Appendix B

AC Electrical Motors data sheet

General purpose aluminum motors

Technical data for totally enclosed squirrel cage three phase motors

EFF2

IP 55 – IC 411 – Insulation class F, temperature rise class B

Output kW	Motor type	Product code	Speed r/min	Efficiency Full load 100%	Efficiency 3/4 load 75%	Power factor cos φ 100%	Current I_N A	Current I_s/I_N	Torque T_N Nm	Torque T_s/T_N	Torque T_{max}/T_N
3000 r/min = 2-poles			400 V 50 Hz				Basic design				
0.09	M2VA 56 A	3GVA 051 001-••A	2820	59.3	53.3	0.69	0.32	3.9	0.31	2.9	2.7
0.12	M2VA 56 B	3GVA 051 002-••A	2840	67.2	63.6	0.64	0.41	4.1	0.41	3.2	2.8
0.18	M2VA 63 A	3GVA 061 001-••C	2820	73.7	70.6	0.64	0.56	4.2	0.62	3.5	3.1
0.25	M2VA 63 B	3GVA 061 002-••C	2810	77.5	78.8	0.71	0.66	4.5	0.87	3.6	3.3
0.37	M2VA 71 A	3GVA 071 001-••C	2840	77.1	76.5	0.72	1	5.5	1.25	3.6	3.9
0.55	M2VA 71 B	3GVA 071 002-••C	2830	79.2	78.2	0.76	1.35	5.7	1.86	3.6	3.7
0.75	M2VA 80 A	3GVA 081 001-••B	2870	81.2	79.3	0.75	1.8	6.2	2.49	2.9	3.6
1.1	M2VA 80 B	3GVA 081 002-••B	2860	81.4	79.5	0.78	2.5	6.1	3.69	2.3	3.5
1.5	M2AA 90 S	3GAA 091 001-••E	2870	80.1	76.2	0.82	3.35	5.5	5	2.4	3.0
2.2	M2AA 90 L	3GAA 091 002-••E	2885	83.6	83.9	0.87	4.37	6.0	7.5	2.5	3.0
3	M2AA 100 L	3GAA 101 001-••E	2900	86.0	84.1	0.88	5.95	7.5	10	2.7	3.6
4	M2AA 112 M	3GAA 111 001-••A	2850	86.0	86.0	0.91	7.4	7.5	13.4	2.8	3.0
5.5	M2AA 132 SA	3GAA 131 001-••A	2855	86.0	86.0	0.88	10.5	6.8	18.3	2.7	3.5
7.5	M2AA 132 SB	3GAA 131 002-••A	2855	87.0	87.0	0.90	13.9	7.2	25	3.2	3.8
11 [1]	M2AA 160 MA	3GAA 161 111-••A	2915	86.4	88.9	0.89	20.5	6.2	36	2.1	2.5
15 [1]	M2AA 160 M	3GAA 161 112-••A	2900	89.5	89.9	0.90	27	6.1	49.4	2.4	2.6
18.5 [1]	M2AA 160 L	3GAA 161 113-••A	2915	90.2	90.5	0.91	32.5	6.8	61	2.6	3.0
22 [1]	M2AA 180 M	3GAA 181 111-••A	2925	91.2	91.3	0.89	39	7.9	72	2.8	3.2
30 [1]	M2AA 200 LA	3GAA 201 011-••A	2945	92.0	92.0	0.88	53	7.9	97	3.0	3.7
37 [1,2]	M2AA 200 L	3GAA 201 012-••A	2945	92.8	92.9	0.89	65	8.2	120	3.1	3.6
45	M2AA 225 M	3GAA 221 011-••A	2940	93.0	93.0	0.88	80	7.7	146	2.8	3.0
55 [1]	M2AA 250 M	3GAA 251 011-••A	2960	93.5	93.8	0.90	95	7.3	177	2.8	3.0

[1] Temperature rise class F for 380 V 50 Hz.
[2] Temperature rise class F for 415 V 50 Hz.

The bullets in the product code indicate choice of mounting arrangement, voltage and frequency, generation code (see ordering information page).

General purpose aluminum motors

Technical data for totally enclosed squirrel cage three phase motors

IP 55 – IC 411 – Insulation class F, temperature rise class B

Output kW	Motor type		Speed r/min (380 V 50 Hz)	Efficiency % (380 V 50 Hz)	Power factor cos φ (380 V 50 Hz)	Current I_N A (380 V 50 Hz)	Speed r/min (415 V 50 Hz)	Efficiency % (415 V 50 Hz)	Power factor cos φ (415 V 50 Hz)	Current I_N A (415 V 50 Hz)	Moment of inertia J=1/4 GD^2 kgm^2	Weight kg	Sound pressure level L_P dB(A)
3000 r/min = 2-poles													
0.09	M2VA	56 A	2805	58.6	0.72	0.32	2930	57.8	0.65	0.34	0.00011	3.2	48
0.12	M2VA	56 B	2825	69.2	0.68	0.4	2850	64.5	0.59	0.45	0.00012	3.4	48
0.18	M2VA	63 A	2815	74.6	0.69	0.53	2830	72.5	0.60	0.56	0.00013	3.9	54
0.25	M2VA	63 B	2800	78.6	0.75	0.64	2830	76.2	0.67	0.69	0.00016	4.1	54
0.37	M2VA	71 A	2830	77.3	0.76	1	2865	75.6	0.68	1.05	0.0004	5.5	58
0.55	M2VA	71 B	2820	80.2	0.81	1.31	2845	77.7	0.73	1.38	0.00045	6.5	56
0.75	M2VA	80 A	2850	82.2	0.80	1.73	2860	79.2	0.68	1.9	0.00072	9	60
1.1	M2VA	80 B	2830	81.1	0.84	2.47	2870	80.2	0.74	2.6	0.00076	11	60
1.5	M2AA	90 S	2850	79.7	0.86	3.4	2890	79.8	0.79	3.4	0.0019	13	63
2.2	M2AA	90 L	2860	83.0	0.89	4.6	2890	83.3	0.84	4.2	0.0024	16	63
3	M2AA	100 L	2890	86.0	0.90	6.15	2910	86.0	0.85	5.95	0.0041	21	65
4	M2AA	112 M	2830	85.0	0.92	7.8	2865	86.5	0.90	7.2	0.01	25	63
5.5	M2AA	132 SA	2840	85.0	0.90	10.9	2865	86.5	0.87	10.2	0.014	37	69
7.5	M2AA	132 SB	2850	86.0	0.91	14.7	2870	87.5	0.83	13.6	0.016	42	69
11	M2AA	160 MA	2905	87.9	0.90	21.5	2920	88.7	0.83	20	0.039	73	73
15	M2AA	160 M	2890	88.9	0.91	28.5	2905	89.8	0.90	26	0.047	84	73
18.5	M2AA	160 L	2905	89.2	0.91	34.5	2925	90.4	0.90	31.5	0.053	94	73
22	M2AA	180 M	2915	90.5	0.91	40.5	2930	91.4	0.87	38.5	0.06	111	75
30	M2AA	200 LA	2940	91.4	0.89	56	2950	92.1	0.86	52	0.084	139	75
37	M2AA	200 L	2940	92.3	0.91	67	2950	92.9	0.88	63	0.115	170	75
45	M2AA	225 M	2940	93.2	0.89	63	2950	93.8	0.87	78	0.21	209	75
55	M2AA	250 M	2955	93.9	0.90	100	2965	94.3	0.66	93	0.31	277	74

Recalculation factors

Recalculation factors for current at rated voltages other than 400 V 50 Hz.			
Rated voltage at 50 Hz and motor wound for	Recalculation factor	Rated voltage at 50 Hz and motor wound for	Recalculation factor
220 V	1.82	500 V	0.80
230 V	1.74	660 V	0.61
415 V	0.96	690 V	0.58

Appendix C

Charts Tables

- **Electric motor chart**

a in 10	a in flat	Frr Nm	Fte Nm	V km	P Kw	G	Fx Nm	W rad/s	T N.m	V rpm
2.12712	1.34768	255	2203.6	1.025733	1884	12.6	5572.8	10.46667	180	100
2.12712	1.34768	255	2203.6	2.051467	3768	12.6	5572.8	20.93333	180	200
2.12712	1.34768	255	2203.6	3.0772	5652	12.6	5572.8	31.4	180	300
2.12712	1.34768	255	2203.6	4.102933	7536	12.6	5572.8	41.86667	180	400
2.12712	1.34768	255	2203.6	5.128667	9420	12.6	5572.8	52.33333	180	500
2.12712	1.34768	255	2203.6	7.180133	13188	12.6	5572.8	73.26667	180	700
2.12712	1.34768	255	2203.6	8.205867	15072	12.6	5572.8	83.73333	180	800
2.12712	1.34768	255	2203.6	10.20092	18650	12.6	5572.8	104.091	180	994.5
1.595415	0.815975	255	2203.6	13.33453	18650	12.6	4243.537	136.0667	137.0652	1300
1.369093	0.589653	255	2203.6	15.386	18650	12.6	3677.732	157	118.7898	1500
1.196023	0.416583	255	2203.6	17.43747	18650	12.6	3245.058	177.9333	104.8145	1700
1.00132	0.22188	255	2203.6	20.51467	18650	12.6	2758.299	209.3333	89.09236	2000
0.857408	0.077968	255	2203.6	23.59187	18650	12.6	2398.521	240.7333	77.47161	2300
0.715274	-0.06417	255	2203.6	27.6948	18650	12.6	2043.185	282.6	65.99434	2700
0.633546	-0.14589	255	2203.6	30.772	18650	12.6	1838.866	314	59.3949	3000
0.566679	-0.21276	255	2203.6	33.8492	18650	12.6	1671.697	345.4	53.99537	3300
0.494389	-0.28505	255	2203.6	37.95213	18650	12.6	1490.973	387.2667	48.15803	3700
0.44966	-0.32978	255	2203.6	41.02933	18650	12.6	1379.15	418.6667	44.54618	4000
0.411172	-0.36827	255	2203.6	44.10653	18650	12.6	1282.93	450.0667	41.43631	4300
0.367498	-0.41194	255	2203.6	48.20947	18650	12.6	1173.744	491.9333	37.91164	4700
0.339328	-0.44011	255	2203.6	51.28667	18650	12.6	1103.32	523.3333	35.63694	5000
0.265773	-0.51367	255	2203.6	61.544	18650	12.6	919.4331	628	29.69745	6000

- **Diesel Engine Chart**

1. Aerodynamic Drag Force (F_{ad}) **(FIGURE 7.5)**

ρ	A(m^2)	Cd	V(Km/h)	V^2(km/h	Fad
1.205	1.9	0.45	0	0	0
1.205	1.9	0.45	10	100	3.97483
1.205	1.9	0.45	20	400	15.8993
1.205	1.9	0.45	30	900	35.7734
1.205	1.9	0.45	40	1600	63.5972
1.205	1.9	0.45	50	2500	99.3707
1.205	1.9	0.45	60	3600	143.094
1.205	1.9	0.45	70	4900	194.766
1.205	1.9	0.45	80	6400	254.389
1.205	1.9	0.45	90	8100	321.961
1.205	1.9	0.45	100	10000	397.483
1.205	1.9	0.45	110	12100	480.954
1.205	1.9	0.45	120	14400	572.375
1.205	1.9	0.45	130	16900	671.746
1.205	1.9	0.45	140	19600	779.066
1.205	1.9	0.45	150	22500	894.336
1.205	1.9	0.45	160	25600	1017.56

2. **Data in Figure (7.8 , 7.9 , 7.10)**

rpm)	ω(rad /s)	P(w)	T(N)	G1	G2	G3	G4	G5
000	104.6667	100000	955.414	3.918	2.261	1.395	1	0.829
000	209.3333	100000	477.707	3.918	2.261	1.395	1	0.829
000	314	100000	318.4713	3.918	2.261	1.395	1	0.829
000	418.6667	100000	238.8535	3.918	2.261	1.395	1	0.829
000	523.3333	100000	191.0828	3.918	2.261	1.395	1	0.829
000	628	100000	159.2357	3.918	2.261	1.395	1	0.829
n	r	Fx1	Fx2	Fx3	Fx4	Fx5	Frr	Fcr 5 in 1
86	0.35	9197.853	5307.898	3274.886	2347.589	1946.151	255	3921.66
86	0.35	4598.926	2653.949	1637.443	1173.794	973.0755	255	3921.66
86	0.35	3065.951	1769.299	1091.629	782.5296	648.717	255	3921.66
86	0.35	2299.463	1326.975	818.7216	586.8972	486.5378	255	3921.66
86	0.35	1839.571	1061.58	654.9773	469.5177	389.2302	255	3921.66
86	0.35	1532.975	884.6497	545.8144	391.2648	324.3585	255	3921.66
ad	V 4km/h	V m/s	Vm/s^2	ρ	A(m^2)	Cd	ΣF	Fcr 10 in 1
49023	45	12.5	156.25	1.205	1.9	0.45	4257.15	1948.65
7665	70	19.44444	378.0864	1.205	1.9	0.45	4371.426	1948.65
7444	92.316	25.64333	657.5805	1.205	1.9	0.45	4515.404	1948.65
2123	123.088	34.19111	1169.032	1.205	1.9	0.45	4778.872	1948.65
9567	153.86	42.73889	1826.613	1.205	1.9	0.45	5117.617	1948.65
4.978	184.632	51.28667	2630.322	1.205	1.9	0.45	5531.638	1948.65

15 in	V5	V3	V2	V1	V	Frr+Fda	Frr+Fad+fcr15
1300	55	35	20	7.854007	10	335.4902	1635.49
1300	85	50	35	15.70801	30	449.7665	1749.766
1300	120	66.17634	44	23.56202	50	593.7444	1893.744
1300	148.4777	88.23513	54.43963	31.41603	70	857.2123	2157.212
1300	185.5971	120	68.04954	39.27004	90	1195.957	2495.957
1300	222.7165	132.3527	81.65944	47.12404	110	1609.978	2909.978

+fcr5	v
76.66	10
76.66	50
76.66	100
76.66	150
76.66	200
76.66	220

Appendix D

Dynamic Coefficient

1. Drag coefficient for different body shapes

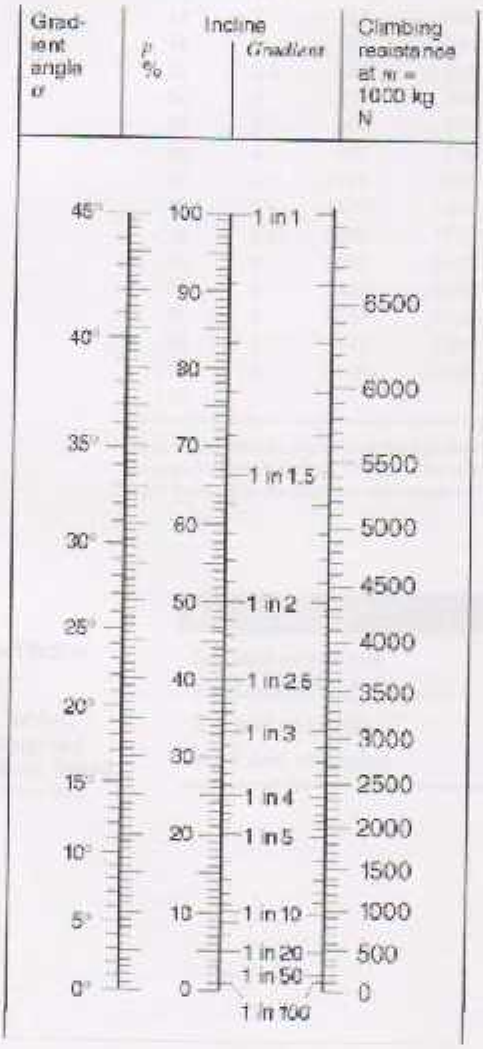
	Drag coefficient cW	Drag power in kW, average values for A = 2 m2 at various speeds 1) 40 km/h	80 km/h	120 km/h	160 km/h
 Open convertible	0.5...0.7	1	7.9	27	63
 Station wagon (2-box)	0.5...0.6	0.91	7.2	24	58
 Conventional form (3-box)	0.4...0.55	0.78	6.3	21	50
 Wedge shape, headlamps and bumpers integrated into body, wheels covered, underbody covered, optimized flow of cooling air.	0.3...0.4	0.58	4.6	16	37
 Headlamps and all wheels enclosed within body, underbody covered	0.2...0.25	0.37	3.0	10	24
 Reversed wedge shape (minimal cross-section at tail)	0.23	0.38	3.0	10	24
 Optimum streamlining	0.15...0.20	0.29	2.3	7.8	18
Trucks, truck-trailer combinations	0.8...1.5	–	–	–	–
Motorcycles	0.6...0.7	–	–	–	–
Buses	0.6...0.7	–	–	–	–
Streamlined buses	0.3...0.4	–	–	–	–

2. Rolling resistance coefficient

Rolling Resistance Coefficients

Conditions	Rolling resistance coefficient
Car tires on concrete or asphalt	0.013
Car tires on rolled gravel	0.02
Tar macadam	0.025
Unpaved road	0.05
Field	0.1–0.35
Truck tires on concrete or asphalt	0.006–0.01
Wheels on rail	0.001–0.002

3. Gradient data sheet



Appendix E

Blot Design

Diameters and Areas of Coarse-Pitch and Fine-Pitch Metric Threads.*

Nominal Major Diameter d mm	Coarse-Pitch Series: Pitch p mm	Coarse-Pitch Series: Tensile-Stress Area A_t mm²	Coarse-Pitch Series: Minor-Diameter Area A_r mm²	Fine-Pitch Series: Pitch p mm	Fine-Pitch Series: Tensile-Stress Area A_t mm²
1.6	0.35	1.27	1.07		
2	0.40	2.07	1.79		
2.5	0.45	3.39	2.98		
3	0.5	5.03	4.47		
3.5	0.6	6.78	6.00		
4	0.7	8.78	7.75		
5	0.8	14.2	12.7		
6	1	20.1	17.9		
8	1.25	36.6	32.8	1	39.2
10	1.5	58.0	52.3	1.25	61.2
12	1.75	84.3	76.3	1.25	92.1
14	2	115	104	1.5	125
16	2	157	144	1.5	167
20	2.5	245	225	1.5	272
24	3	353	324	2	384
30	3.5	561	519	2	621
36	4	817	759	2	915
42	4.5	1120	1050	2	1260
48	5	1470	1380	2	1670
56	5.5	2030	1910	2	2300
64	6	2680	2520	2	3030
72	6	3460	3280	2	3860
80	6	4340	4140	1.5	4850
90	6	5590	5360	2	6100
100	6	6990	6740	2	7560
110				2	9180

*The equations and data used to develop this table have been obtained from ANSI B1.1-1974 and B18.3.1-1978. Th[illegible] diameter was found from the equation $d_r = d - 1.226\,869p$, and the pitch diameter from $d_p = d - 0.649\,519p$. [illegible] the pitch diameter and the minor diameter was used to compute the tensile-stress area.

Thrust-Collar Friction Coefficients

Source: H. A. Rothbart, *Mechanical Design and Systems Handbook*, 2nd ed., McGraw-Hill, New York, 1985.

Combination	Running	Sta
Soft steel on cast iron	0.12	0.
Hard steel on cast iron	0.09	0.
Soft steel on bronze	0.08	0.
Hard steel on bronze	0.06	0.

Dimensions of Hexagonal Nuts

Nominal Size, in	Width W	Height H: Regular Hexagonal	Height H: Thick or Slotted
$\frac{1}{4}$	$\frac{7}{16}$	$\frac{7}{32}$	$\frac{9}{32}$
$\frac{5}{16}$	$\frac{1}{2}$	$\frac{17}{64}$	$\frac{21}{64}$
$\frac{3}{8}$	$\frac{9}{16}$	$\frac{21}{64}$	$\frac{13}{32}$
$\frac{7}{16}$	$\frac{11}{16}$	$\frac{3}{8}$	$\frac{29}{64}$
$\frac{1}{2}$	$\frac{3}{4}$	$\frac{7}{16}$	$\frac{9}{16}$
$\frac{9}{16}$	$\frac{7}{8}$	$\frac{31}{64}$	$\frac{39}{64}$
$\frac{5}{8}$	$\frac{15}{16}$	$\frac{35}{64}$	$\frac{23}{32}$
$\frac{3}{4}$	$1\frac{1}{8}$	$\frac{41}{64}$	$\frac{13}{16}$
$\frac{7}{8}$	$1\frac{5}{16}$	$\frac{3}{4}$	$\frac{29}{32}$
1	$1\frac{1}{2}$	$\frac{55}{64}$	1
$1\frac{1}{8}$	$1\frac{11}{16}$	$\frac{31}{32}$	$1\frac{5}{32}$
$1\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{1}{4}$
$1\frac{3}{8}$	$2\frac{1}{16}$	$1\frac{11}{64}$	$1\frac{3}{8}$
$1\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{9}{32}$	$1\frac{1}{2}$
Nominal Size, mm			
M5	8	4.7	5.1
M6	10	5.2	5.7
M8	13	6.8	7.5
M10	16	8.4	9.3
M12	18	10.8	12.0
M14	21	12.8	14.1
M16	24	14.8	16.4
M20	30	18.0	20.3
M24	36	21.5	23.9
M30	46	25.6	28.6
M36	55	31.0	34.7

Preferred Sizes and Renard (R-Series) Numbers
(When a choice can be made, use one of these sizes; however, not all parts or items are available in all the sizes shown in the table.)

Fraction of Inches

$\frac{1}{64}, \frac{1}{32}, \frac{1}{16}, \frac{3}{32}, \frac{1}{8}, \frac{5}{32}, \frac{3}{16}, \frac{1}{4}, \frac{5}{16}, \frac{3}{8}, \frac{7}{16}, \frac{1}{2}, \frac{9}{16}, \frac{5}{8}, \frac{11}{16}, \frac{3}{4}, \frac{7}{8}, 1, 1\frac{1}{4}, 1\frac{1}{2}, 1\frac{3}{4}$,
$2\frac{1}{4}, 2\frac{1}{2}, 3, 3\frac{1}{4}, 3\frac{1}{2}, 3\frac{3}{4}, 4, 4\frac{1}{4}, 4\frac{1}{2}, 4\frac{3}{4}, 5, 5\frac{1}{4}, 5\frac{1}{2}, 5\frac{3}{4}, 6, 6\frac{1}{2}, 7, 7\frac{1}{2}, 8, 8\frac{1}{2}$,
$10, 10\frac{1}{2}, 11, 11\frac{1}{2}, 12, 12\frac{1}{2}, 13, 13\frac{1}{2}, 14, 14\frac{1}{2}, 15, 15\frac{1}{2}, 16, 16\frac{1}{2}, 17, 17\frac{1}{2}, 18$,
$18\frac{1}{2}, 19, 19\frac{1}{2}, 20$

Decimal Inches

0.010, 0.012, 0.016, 0.020, 0.025, 0.032, 0.040, 0.05, 0.06, 0.08, 0.10,
0.20, 0.24, 0.30, 0.40, 0.50, 0.60, 0.80, 1.00, 1.20, 1.40, 1.60, 1.80, 2.0,
2.8, 3.0, 3.2, 3.4, 3.6, 3.8, 4.0, 4.2, 4.4, 4.6, 4.8, 5.0, 5.2, 5.4, 5.6, 5.8, 6.0,
8.5, 9.0, 9.5, 10.0, 10.5, 11.0, 11.5, 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0,
16.0, 16.5, 17.0, 17.5, 18.0, 18.5, 19.0, 19.5, 20

Millimeters

0.05, 0.06, 0.08, 0.10, 0.12, 0.16, 0.20, 0.25, 0.30, 0.40, 0.50, 0.60, 0.70,
0.90, 1.0, 1.1, 1.2, 1.4, 1.5, 1.6, 1.8, 2.0, 2.2, 2.5, 2.8, 3.0, 3.5, 4.0, 4.5, 5.0,
6.0, 6.5, 7.0, 8.0, 9.0, 10, 11, 12, 14, 16, 18, 20, 22, 25, 28, 30, 32, 35, 40, 45,
60, 80, 100, 120, 140, 160, 180, 200, 250, 300

Renard Numbers*

1st choice, R5: 1, 1.6, 2.5, 4, 6.3, 10
2d choice, R10: 1.25, 2, 3.15, 5, 8
3d choice, R20: 1.12, 1.4, 1.8, 2.24, 2.8, 3.55, 4.5, 5.6, 7.1, 9
4th choice, R40: 1.06, 1.18, 1.32, 1.5, 1.7, 1.9, 2.12, 2.36, 2.65, 3, 3.35, 3.75,
4.25, 4.75, 5.3, 6, 6.7, 7.5, 8.5, 9.5

*May be multiplied or divided by powers of 10

Appendix F

Inverter Wiring Connection

Users must connect wires according to the following circuit diagram shown below. Do n plug a Modem or telephone line to the RS-485 communication port, permanent damag result. Pins 1 & 2 are the power sources for the optional copy keypad and should not b used while using RS-485 communication.

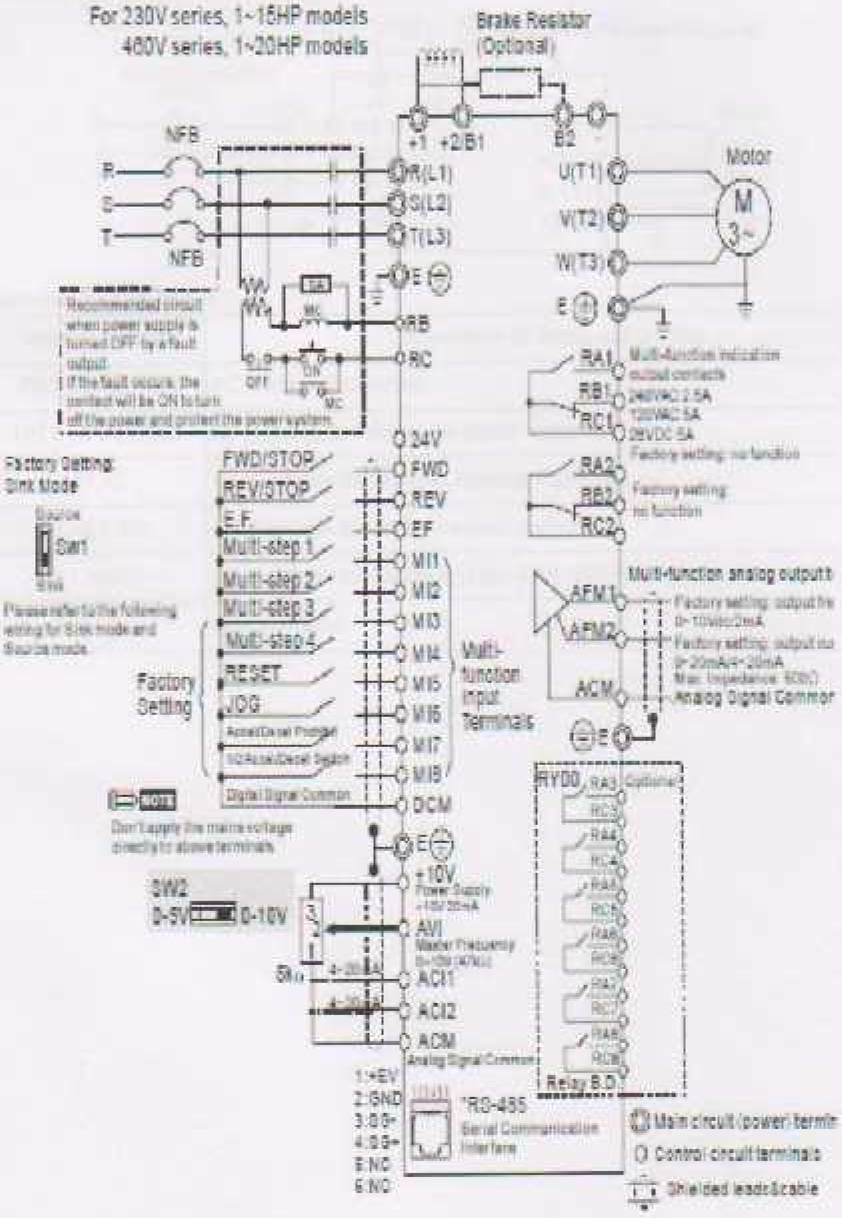


Figure 1 for the main circuit terminals

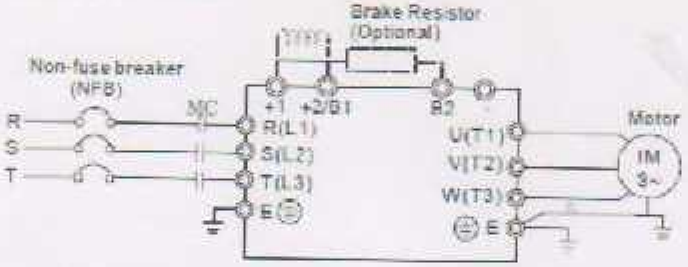
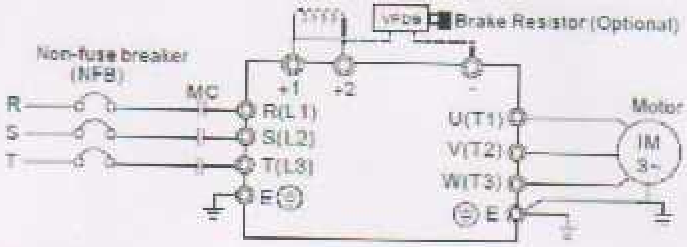


Figure 2 for the main circuit terminals



Terminal Explanations

Terminal Symbol	Explanation of Terminal Function
R/L1, S/L2, T/L3	AC line input terminals
U/T1, V/T2, W/T3	AC drive output terminals motor connections
+1,+2	Connections for DC Link Reactor (optional)
+2/B1~B2	Connections for Brake Resistor (optional)
+2~ -,+2/B1~ -	Connections for External Brake Unit (VFDB series)
⏚	Earth Ground