**DEVELOPING DRIVELINE SYSTEM FOR SOLAR POWER VEHICE**

MECH5845M Professional Project

***<DEVELOPING DRIVELINE SYSTEM FOR SOLAR POWER VEHICE>***

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**ABSTRACT**

The new designs and methods to develop a compact and effective driveline for solar power vehicle are presented in this thesis. The results obtained from calculations and research were analysed to develop the driveline efficiency for the vehicle. An existing solar power vehicle was redesigned with a new driveline circuit and an advanced control strategy. The implementation platform is a solar power compact vehicle which is meant to run with 100 percent solar energy with a conventional electric vehicle driveline system. A model design of the current electric vehicle driveline was considered for simulating and calculating the efficiency of the driveline. Various driveline components where considered for simulating to know their role in reducing the efficiency of the driveline. The direct drive concept was considered to increase the efficiency by reducing a greater number of vibrating components. Calculations were made to improve efficiency by eliminating components. The feasible design was developed with improved efficiency. Now, after attaining the max power output we must improve stiffness at the wheels while cornering and slip. A new design of motor was considered for independent power distribution to the wheels. Some calculations were made and new type of controller where considered after intense research for proper positioning of the wheel. Simulating the calculations and after proper study of the graphs the feasible control system was developed to improve stiffness.

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# Chapter 1

# Introduction

## Introduction

In recent decades, consumption of crude oil in the transportation sector has increased at a

higher rate than any other sector. Statistics has described that, with current resources of oil and current consumption, the world crude oil resources will be drained by 2049. The increase in consumption has come from developing high power demands of IC engines.

The enormous utilization of IC engines vehicles has contributed in rise of medium and large cities pollutions. Since the vehicle pollutions are the major role in increase of greenhouse effect and global warming the government agencies and organizations have developed rigorous standards for fuel consumption and emissions.

Initiative to address this issue would be to implement Electric Vehicles (EVs) because of zero consumption of oil and zero emissions, but they are not the most viable solution because of less charging points in cities and they transfer the emission to power generation industries. Many vehicle journeys made in cities are of short range and of low speed. Therefore, these parameters are well-suited to a solar powered vehicle (SPV). The zero local emissions and the silent driving of the solar power vehicles vehicles are few attributes that can help to restore the quality of life in cities [2]. For short distances and heavy traffic conditions in cities solar power vehicles can give better performances than IC engine vehicles [2,4].

Due to the high cost of solar panels and equipment they might be expensive for high power demands. Therefore, they are initially designed compact and lighter for short range. Hence to improve the range of the solar power vehicle a new driveline must be developed which can reduce the power loss due to some mechanical parts.

**1.2 History of Solar Power Vehicles**

The first solar power vehicle was invented by William G. Cobb of General Motors. It was a 15 Inch tiny vehicle Called the Sunmobile. William Cobb had showcased the first solar car at the Chicago Powerama convention on August 31, 1955. The solar power vehicle was built up with 12 selenium photovoltaic cells and a small Pooley electric motor turning a pulley which in turn rotated the rear wheel shaft. The first solar power vehicle in history was too small to drive.

|  |  |
| --- | --- |
| First Solar Car |  |

Later, in 1962 the first solar power vehicle that a person could drive was introduced to the public. The International Rectifier Company developed a vintage model 1912 Baker electric car (pictured above) to run on photovoltaic energy in 1958, but it wasn’t displayed until 4 years later. Around 10,640 individual solar cells were mounted to the rooftop of the Baker to help propel it.

Then in 1977, Alabama University professor Ed Passereni built the Bluebird solar car, which was a prototype vehicle. The Bluebird was supposed to run with the help of solar energy directly without batteries. The Bluebird was exhibited in the Knoxville, TN 1982 World's Fair.

Between 1977 and 1980, at Tokyo Denki University, professor Masaharu Fujita first created a solar bicycle, then a 4-wheel solar car. The car was two solar bicycles put together.

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| https://www.automostory.com/images/freeman-solar-car.jpg |  |

***In 1979 Englishman Alain Freeman invented a solar car (pictured right). He road registered the same vehicle in 1980. The Freeman solar car was a 3-wheeler with a solar panel on the roof.***

In the engineering department of Tel Aviv University in Israel, Arye Braunstein and his colleagues created a solar car in 1980 (pictured below). The solar car had solar panels on hood and roof of the Citi car comprised of 432 cells creating 400 watts of peak power. The solar car used 8 batteries of 6 volts each to store the photovoltaic energy.

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| https://www.automostory.com/images/israel-solar-citicar.jpg |  |

***The 1,320-pound solar Citi car is said by the engineering department to have been able to reach up to 40 mph with a maximum range of 50 miles.***

In 1981 Hans Tholstrup and Larry Perkins developed a solar powered racecar. In 1982, the both became the first to cross a continent in a solar car, from Perth to Sydney, Australia. Tholstrup is the initiator of the World Solar Challenge in Australia.

In 1984, Greg Johanson and Joel Davidson discovered the Sunrunner solar race car. The Sunrunner set the official Guinness world record in Bellflower, California of 24.7 mph. In the Mojave Desert of California and final top speed of 41 mph was officially recorded for a "Solely Solar Powered Vehicle" (did not use a battery). The 1986 Guinness Book of World Records publicized these official records.

The GM Sunraycer in 1987 completed an 1,866-mile trip with an average speed of 42 mph. Since then there have been many solar cars invented at universities for competitions such as the Shell Eco Marathon. There is also a commercially available solar car called the Venturi Astrolab. Time will only tell how far the solar car makes it with today's and tomorrow's technology.

* 1. **Motivation for Research**

Due to shifting of emissions from vehicles to power generation industries and high initial cost of implementing renewable resources for power generation made solar power cars more demanding for the future. Hence considering these conditions lead the world to Solar Power Vehicle which can be powered completely or partially by solar energy with help of Photo-Voltaic cells implanted in the solar panels to convert energy from sun directly into electricity. Therefore, 100 percent solar powered vehicle is considered because of the developing pollution as a never-ending process. Hence to increase the efficiency and range of the solar vehicle, it is designed to be very compact and lightweight. Meanwhile considering the above factors the driveline is to be designed in a manner that it can support the vehicle for proper handling, overall weight and performance. Power losses are reduced, and efficiency is increased by eliminating mechanical components, therefore this also creates more space in the chassis which can be utilized for installing more batteries. The life cycle of driveline is increased, and maintenance cost is reduced by eliminating components prone to wear. The stiffness is improved by proper positioning and proper power distribution. A new motor design is considered for independent power supply to wheels in order to replace the differential.

**1.4 Thesis Overview**

Chapter II of the thesis provides the necessary background information of an

electric vehicle drivetrain and briefly explains the electric vehicle developed in this

research. An overview of the different vehicle architectures considered for converting the existing electric vehicle into a plug-in hybrid electric vehicle are discussed. The approach

considered for modeling the electric vehicle in Matlab – Simulink software is discussed.

The different stages in the process of developing the electric vehicle drivetrain are

explained.

Chapter III explains the development of a Matlab-Simulink model for the EV

under research. An equivalent electrical circuit model for the Li-ion batteries used in the

vehicle is developed based on experimental data. Control strategies for the developed

electric vehicle and series PHEV models are discussed. Development of models for

different drivetrain sub-systems is also presented.

Chapter IV presents the simulation results of the electric vehicle model developed

in Matlab-Simulink environment. The analysis based on the simulation results is

presented. The feasibility of converting the existing electric vehicle into a series PHEV is

discussed along with simulation results.

Chapter V describes various hardware components used in the vehicle with their

layouts. The control algorithm developed for the vehicle is discussed. It also presents the

real time error diagnostics implemented in the vehicle.

The results and analysis based on the real time data logged during the tests on

vehicle lift and on road operation are discussed in Chapter VI. The vehicle

communications and the display of real world driving statistics to driver are explained.

Chapter VII

# Chapter 2

# BACKGROUND WORK

* 1. **Introduction to driveline systems**

A vehicle depends on its wheels for motion and the wheels are dependent on power from engine for motion. Therefore, for the transfer of power from engine to wheels they need a set of components called driveline. Vehicles are existing for past two centuries and many models have been developed depending on the currents demands of those times, drivelines are one of those vehicle systems which have been developed depending on increasing high performance demands for centuries. Few of those drivelines are being discussed below.

1. **Conventional IC engine Transmission**

A conventional driveline transfers power generated from engine to the wheels through gear transmission, shaft and differential. The torque and speed are being controlled by gear transmission with help of different gear combinations (gear ratios). Due to the ideal engine speed which remains constant for efficient operation the gearbox ratio must be changed, either manually, automatically or by an automatic continuous variation. The differential adapts amount of friction between wheel and surface and distributes power as required by each wheel. These conventional drivelines have been developed in different combination depending on the current trends and demands. The layouts of these different combinations are being discussed below.

**Rear Wheel Drive:**

**A close up of a device

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The above diagram shows a typical rear-wheel-drive layout. Rear-wheel drive (RWD) consist of engine at the front end of the chassis and driven wheels at the rear then this configuration is known as front-engine, rear-wheel-drive layout (FR layout). The front mid-engine, rear mid-engine and rear engine layouts are also used. This was the traditional layout for majority of the vehicles up until the 1970s and 1980s. almost all motorcycles and bicycles uses rear-wheel drive mechanism, either by driveshaft, chain, or belt. Since the front wheel is turned for steering it would be very difficult to "bend" the drive mechanism while turning the front wheel. It would be a rare exception with the 'moving bottom bracket' type of recumbent bicycle, where the entire drivetrain, including pedals and chain, pivot with the steering front wheel. Majority of rear-wheel-drive vehicles consists of a longitudinally mounted engine in the front of the vehicle, driving the rear wheels via a driveshaft connected via a differential between the rear axles. Some FR layout vehicles place the gearbox at the rear, though most attach it to the engine at the front. The FR layout is often chosen for its simple design and good handling characteristics.

**Advantages**

* Even weight distribution - The layout of a rear-wheel-drive car is much closer to an even weight distribution between front and rear axles than a front-wheel-drive car.
* Weight transfer during acceleration - During high acceleration, weight is shifted to the rear, or driving wheels, which improves traction.
* Better handling at the hands of an expert - the more even weight is distributed. Weight transfer improve the handling of the car. More even loads are placed on front and rear tyres, which allows for more grip while cornering.
* Better braking - the more even weight distribution helps preventing rear wheel lockups and becoming unloaded under heavy braking.
* Can adapt more powerful engine layouts as a result of the longitudinal orientation of the drivetrain, such as the inline-6, 90° big-bore V8, V10 and V12 making the FR a common configuration for luxury and sports cars. These engines are usually too long to fit in an FF transverse engine ("east-west") layout; the FF configuration can typically accommodate at the maximum an inline-4 or V6.
* Road grip feedback - front wheels are not affected by engine and gearbox, thus allowing for better feeling of tyre grip on road surface.

### **Disadvantages**

* Under heavy acceleration (racing), oversteer and fishtailing may occur as the rear wheels might spin. The corrective action for this is to off the throttle.
* On snow, ice and sand, rear-wheel drive loses its traction compared to front and all-wheel drive.
* Decreased interior space - Rear-wheel drive vehicles may have less front leg room as the transmission tunnel occupies the space between the driver and front passenger, less leg room for centre rear passengers (due to the tunnel needed for the drive shaft),
* Increased weight - The rear-wheel-drive vehicle's power train components are less complex, but they are larger. The driveshaft adds weight. There use of extra sheet metal to form the transmission tunnel. The rear axle or rear half-shafts are typically longer than those in a front-wheel-drive car. A rear-wheel-drive car will weigh slightly more than a front-wheel-drive car (but less than four-wheel drive).
* The possibility of losses in the mechanical efficiency of the drivetrain (approximately 17% coast down losses between engine flywheel and road wheels compared to 15% for front-wheel drive - however these losses are highly dependent on the individual transmission). Cars with rear engine or mid-engine configuration and a transverse engine layout do not suffer from this.

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**Front wheel drive**

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Front-wheel-drive layout defines that the front wheels of the vehicle are driven. The most popular layout used in cars today is the front-engine, front-wheel drive. Here, the engine is transversely mounted in front of the front axle, driving the front wheels. This layout is typically chosen for its compact packaging. Since the engine and driven wheels are on the same side of the vehicle, the need for the central tunnel through the passenger compartment for mounting a prop-shaft between the engine and the driven wheels is eliminated.

As the steered wheels and the driven wheels are same, FF (front-engine, front-wheel-drive layout) cars are always considered superior to FR (front-engine, rear-wheel-drive layout) cars in low-traction conditions such as snow, mud, or wet tarmac. The weight of the engine over the driven wheels also improves grip in such conditions.

A transverse engine (also known as "east-west") is commonly used in FF designs, in contrast to FR which uses a longitudinal engine. The FF layout also limits the size of the engine, as FF configurations usually have inline-4 and V6 engines, while longer engines such as inline-6 and 90° V8 will rarely fit. This is another reason luxury/sports car avoid the FF layout. Exceptions do exist, such as the Volvo S80 (FWD/4WD) which uses transversely mounted inline-6 and V8 engines, and the Ford Taurus SHO, available with a 60° V8 and front-wheel drive.

### **Advantages**

* Interior space: Since the powertrain is a single unit contained in the engine compartment of the vehicle, there is no need to sacrifice interior space for a driveshaft tunnel or rear differential, increasing the volume available for passengers and cargo.
* Weight: Fewer components usually means lower weight.
* Improved fuel efficiency due to less weight.
* Improved drivetrain efficiency: the direct connection between engine and transaxle reduce the mass and mechanical inertia of the drivetrain improving fuel economy.

### **Disadvantages**

* Front-engine front-wheel-drive layouts are "nose heavy" with more weight distribution forward, which makes them prone to understeer, especially in high horsepower applications.
* Torque steer is the tendency for some front-wheel-drive cars to pull to the left or right under hard acceleration.
* Due to geometry and packaging constraints, the CV joints (constant-velocity joints) attached to the wheel hub have a tendency to wear out much earlier than the universal joints typically used in their rear-wheel-drive counterparts.
* Turning circle - FF layouts almost always use a transverse engine ("east-west") installation, which limits the amount by which the front wheels can turn, thus increasing the turning circle of a front-wheel-drive car compared to a rear-wheel-drive one with the same wheelbase
* The FF transverse engine layout (also known as "east-west") restricts the size of the engine that can be placed in modern engine compartments, so it is rarely adopted by powerful luxury and sports cars.

## Four-wheel-drive

Most 4WD layouts are front-engine and are derivatives of earlier front-engine, two-wheel-drive designs. They fall into two major categories:

* Front-engine, rear-wheel drive derived 4WD systems, standard in most sport vehicles and in passenger cars, (frequently referred to as "front engine, rear-wheel drive/four-wheel drive).
* Transverse and longitudinal engine 4WD systems derived almost exclusively from front-engine, front-drive layouts, fitted to luxury, sporting and heavy-duty segments.

### **Advantages**

In terms of handling, traction and performance, 4WD systems generally have most of the advantages of both front-wheel drive *and* rear-wheel drive. Some unique benefits are:

* Traction is nearly doubled compared to a two-wheel-drive layout.
* Gives enough power, this results in unparalleled acceleration and driveability on surfaces with less than ideal grip, and superior engine braking on loose surfaces.
* Handling characteristics in normal conditions can be configured to emulate FWD or RWD, or some mixture, even to switch between these behaviours according to circumstance.

**Disadvantages**

* Four-wheel drive systems have complex transmission layout, and so increase the manufacturing cost of the vehicle and maintenance procedures and repairs compared to 2WD designs
* Four-wheel drive systems increase powertrain mass, rotational inertia and power transmission losses, resulting in performance reductions in ideal dry conditions and increased fuel consumption.

**Electric Conventional Driveline**

Single and Multi-motor drives, in wheel drives Electric Vehicle (EV) Configurations when compared to HEV the configuration of EV is flexible. The reasons for this flexibility are: The energy flow via flexible electrical wires rather than mechanical components. Hence, distributed subsystems in the EV are achievable. The EVs allow different propulsion arrangements such as independent four wheels and in wheel drives. In Figure 1 the general configuration of the EV is shown.

The EV has three major subsystems:

* Electric propulsion
* Energy source
* Auxiliary system

The electric propulsion subsystem comprises of:

* The electronic controller
* Power converter
* Electric Motor (EM)
* Mechanical transmission
* Driving wheels

In Figure 1 the black line represents the mechanical link, the green line represents the electrical link and the blue line represents the control information communication. Based on the control inputs from the brake and accelerator pedals, the electronic controller provides control signals to switch on or off the power converter which in turn regulates the power flow between the electric motor and the energy source. The backward power flow is due to regenerative braking of the EV. This regenerative energy can be stored. The energy management unit co-operates with the electronic controller to control regenerative braking and energy recovery. The auxiliary power supply provides the necessary power with different voltage levels for all EV auxiliaries, especially the temperature control and power steering units.

![A screenshot of a cell phone

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**General Configuration of a Electric Vehicle**

In modern EV’s configuration:

* Three phase motors are generally used to provide the traction force
* The power converter is a three-phase PWM inverter
* Mechanical transmission is based on fixed gearing and a differential
* Li-ion battery is typically selected as the energy source

**Electric Vehicle (EV) Drivetrain Alternatives Based on Drivetrain Configuration**

There are different possible EV configurations due the variations in electric propulsion and energy sources. Based on these variations, six alternatives are shown in Figure. These six alternatives are

* In Figure A a single electric motor (EM) configuration with gearbox (GB) and a clutch is shown. It consists of an EM, a clutch (C), a gearbox, and a differential (D). The clutch allows the power flow from EM to the wheels. The gear transmission consists of a set of gears with different gear ratios. With the use of clutch and gearbox, the driver can shift the gears which changes the torque going to the wheels. The wheels have high torque low speed in the lower gears and high-speed low torque in the higher gears.
* In Figure B a single electric motor (EM) configuration without the gearbox and the clutch is shown. The advantage of this configuration is to reduce the weight of the vehicle. However, this configuration demands a more complex control of the EM to provide the necessary torque to the wheels.
* Figure C a configuration of EV using one EM is shown. It is a transverse drive configuration. It has a fixed gearing and differential and they are integrated into a single assembly.
* In Figure D shows a dual motor configuration. In this configuration the differential action can be while cornering can be replaced by two electric motors.
* In order to shorten the drivetrain configuration and give more effective and efficient energy to wheels, the EM can be placed inside a wheel. This configuration is called in-wheel drive. Figure E shows this configuration in which fixed planetary gearing is employed to reduce the motor speed to the required wheel speed.
* In Figure F an EV configuration without any mechanical gearing is shown. By fully abandoning any mechanical gearing, the in-wheel drive can be realized by installing a low speed outer-rotor electric motor inside a wheel.

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**Single and Multi-motor Drives**

A differential is a standard component for conventional vehicles. When a vehicle is traveling a curved road, the outer wheel needs to travel on a larger radius than the inner wheel. Thus, the differential adjusts the relative speeds of the wheels. If relative speeds of the wheels are not adjusted, then the wheels will slip and result in tire wear, steering difficulties and poor road holding. In EVs, it is possible to dispense the mechanical differential by using two or more EMs. With the use of multiple EMs, each wheel can be coupled to an EM and this will enable independent control of speed of each wheel in such a way that the differential action can be electronically achieved. In Figure, a typical dual motor drive with an electronic differential is shown.

![A close up of a lamp

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**Direct Drive Systems**

Direct-drive motors work similar to other brushless dc motors. Magnets on the motor’s rotor and windings on the motor’s stator interact when they get energized. Then the windings produce electromagnetic fields that attract or repel the rotor’s magnets. Precise commutation of power to the winding’s spurs-controlled motion. Both rotary and linear direct-drive motors exist, but rotary types are most common.

Direct-drive motors usually have 30 poles and sometimes even more than 100. This lets them output high torque at no or low speed, slower than 1,000 rpm. Direct-drive motors bigger than 3 ft (1 m) can produce torque of more than 10,000 Nm. Many direct-drive motors are frameless.

Direct-drive motors have higher torque-to-inertia ratios, and they have a low electrical time constant. So, the motors rapid output torque when supplies feed voltage to the windings getting “good servo stiffness.” More traditional motors generate maximum torque at higher speeds, typically at speeds greater than 1,000 rpm, and engineers’ size and specify them on their power rating.

#### **Advantages**

* Direct drives offer superb dynamic performance and accurate control of position and speed.
* They are reliable and exhibit no backlash or wear due to the low part count and elimination of gears, pulleys, seals and bearings.
* Low torque ripple or cogging
* Low acoustic noise and minimal self-induced vibration, with low axial height and large bore
* High torque-to-inertia ratio and high torque-to-mass ratio;
* High torque at low speeds
* Energy efficiency by elimination of intermediate mechanical friction and inertia
* Relatively large airgaps to resist shock and survive dirty environments  
   minimal cooling requirements due to advantageous thermal geometry.

**Disadvantages**

* The high cost is often exaggerated.
* Direct-drive motors are more expensive than traditional motors in a simple 1:1 comparison.
* However, cost analysis that accounts for the savings in omitting intermediate gears and couplings (and associated maintenance) and overall mechanical simplification often finds direct-drive arrangements the most cost-effective option.
* What’s more, the cost premium for direct-drive motors is coming down as direct drives are increasingly common, and there’s more availability of powerful neodymium-iron-boron (Nd-Fe-B) magnets.
* Direct-drive units suffer more from ripple of motor torque and cogging unless the motor controls use feedback to counteract the effect.
* One factor that may have slowed the uptake of direct-drive motors is that they need precise electrical control.