A Project Report on

MILD HYBRID ELECTRIC VEHICLE

Submitted to

Savitribai Phule Pune University, Pune

For the partial fulfilment of the award of degree of Bachelor of Engineering in Instrumentation and Control

Submitted By

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June 2021

Government College of Engineering and Research,

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CERTIFICATE

This is to certify that, the following students have successfully completed the project work entitled "***Mild Hybrid Electric Vehicle***" in the partial fulfilment of the award of degree in Bachelor of Engineering in Instrumentation and Control of Savitribai Phule Pune University, Pune.

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Vision and Mission of the Institute

Institute Vision

- Educational institution for Empowerment through technological excellence towards sustainable development

Institute Mission

- Value based and demand driven education using best practices
- Promotion of research, innovation and entrepreneurship
- Commitment to sustainable solutions in service of society
- Capability to face global challenges

Program Outcomes (POs)

Engineering Graduates will be able to:

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/Development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The Engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal. Health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

ACKNOWLEDGEMENT

While doing project work, we received continued guidance, cooperation and motivation from the project approval committee of the Instrumentation & Control Engineering department. We are sincerely thankful to the committee. It is our foremost duty to express gratitude and respect to **Dr. A. S. Pant**, Principal, Government college of Engineering and Research, Avasari (Kh), Pune. We are also grateful to the Head of Instrumentation & Control Department **Dr. N. S. Nehe** for his support.

We are very much thankful to our project guide **Dr. N. S. Nehe** for giving us useful and valuable guidance so as to complete the project work.

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ABSTRACT

As the world is concerned about climate change, all countries strive for clean energy and In India 27% of pollution is caused by vehicles hence the automotive industry is researching into improving the efficiency of automobiles. Conventional vehicles provide good performance and long range. But due to low fuel economy and exhaust gas emissions causing environmental pollution, interest in electric/hybrid vehicles is increasing. Hybrid vehicle systems were proposed and have demonstrated the capability of reducing fuel consumption while maintaining vehicle performance. A hybrid electric vehicle has two sources of torque, the internal combustion engine (ICE) and an electric motor (EM). The energy for the ICE comes from the fuel tank and for the EM from a high voltage battery.

The main reason to create a Hybrid vehicle model in MATLAB is to demonstrate its fuel economy improvement over a conventional vehicle system. In the model used the Volkswagen Polo specifications. The electric motor acts as a supplement to the engine torque. The motor unit also acts as a generator during regenerative braking to recover the otherwise lost kinetic energy. The powertrain components power output calculation and the control logic were modelled in MATLAB/Simulink. The model utilizes a driver input simulation, where the driver control module compares the actual and desired speeds, and applies a throttle or a braking percent to the powertrain components, which in turns applies the driving or the braking torque to the wheels.

The results obtained from the Hybrid vehicle model are compared with conventional vehicle model for the WLTP drive cycles. The hybrid vehicle demonstrated 9.68% fuel economy improvement and 25% less emission over the conventional vehicle model for WLTP-2 cycle.

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Chapter 1

INTRODUCTION TO MILD HYBRID VEHICLE

1.1 Introduction

As the global economy strives towards clean energy in the face of climate change, the industrial world is researching alternative sources of energy. Since automobiles are currently a major source of air pollution, governments and major automotive companies are collaborating to provide a solution that will result in the reduction of vehicle emissions, while reducing the consumption of fossil fuel. Various forms of fossil fuel reduction methods and alternative power sources are currently researched by different manufacturers. The two notable categories in research are internal combustion (IC) engine vehicles and electric vehicles. Fuels presently utilized in internal combustion engine vehicles include turbo or supercharging gasoline, diesel, methanol, and natural gas. The energy path of the IC engine is to transform the energy content of various fuel sources into kinetic energy that propels the vehicle forward. This is accomplished by using the expansion of burning fuel in a chamber to provide a translational motion to propel the wheels. The advantage of IC engines is that fuels with high-energy content can be transported easily, while the disadvantage is that the burning of fuels creates emissions that are hazardous to the environment. Alternatively, the electric vehicle uses electric energy from a battery or fuel cell, and converts it into kinetic energy via electric motors. The advantage of an electric vehicle is that zero emissions are produced when the electric energy is converted into kinetic energy. Various methods of providing electric energy are currently being explored. Conventional battery is one method of storing electric energy, although current technologies prevent a working solution with reasonable vehicle mileage. Hydrogen fuel cells are an alternative method of storing electrical energy; however, current technologies have not matured yet to provide a safe storage of hydrogen.

In search of a working solution, a hybrid vehicle system which combines the advantages of both power sources (IC engine and battery), was proposed. By definition, a hybrid vehicle is one that employs two or more power sources to improve the overall efficiency of the vehicle. By combining an internal combustion engine with an electric battery-motor system, the goal of fuel portability can be solved. In addition to achieving low emission and fuel consumption requirements, hybrid electric vehicles can recapture the otherwise lost kinetic energy during the braking cycle, thus further improving the efficiency of the vehicle system.

1.2 Literature Survey:

The work carried out in the field of Hybrid vehicles by the researchers worldwide and published in various articles in National/International journals, reference books and IEEE conferences proceedings that used for the present investigation, has been reviewed and presented here in brief.

As we went through various articles here are some brief points from the articles.considering the Current scenario of electric vehicles in India

Lack of EV Charging Infrastructure:

A major challenge for the EV industry in India is the lack of adequate charging infrastructure in India. Apart from a few metros, there are really fewer charging stations which makes it very difficult for daily users to switch over EVs.Despite the recent policy of the Indian government for the installation of charging stations across major highways, very few can be seen until today. It makes driving and traveling far from the city by an EV almost impossible. Makes the major reason for challenges for EV in India.

The initial cost of owning:

Due to the higher cost of EV technology, the price tag of electric vehicles in India can be a big turn-off. The cost of owning a traditional ICE (internal combustion engine) car is around 5-6 Lakhs but the minimum cost of electric cars in India is around 16 lacs, which is too high for the Indian middle-class majority. The 2x price of electric cars in the Indian economy can be a major challenge for EV companies to tackle. As per reports, the increase in price is due to the import of a lot of parts and components in electric vehicles, which is a major challenge for electric vehicles in India.

Cost of battery:

The unavailability of lithium reserves in India and the need to import it from other countries makes the cost of buying electric vehicle batteries very high. The average cost of an electric car battery in India is around 2.1 Lakhs.India doesn't produce any lithium-ion batteries to be used in EVs as we don't have many Lithium reserves in India. The need to replace batteries after 7-8 years, makes it really costly to own an EV in India at this time.

Charging time & Range Issue:

The wait time to charge an electric vehicle can be a major hurdle for EV companies to tackle. Not all vehicles launched to date are equipped with flash charge technology.and The poor range of EVs in India turns off Indian consumers as it is next to impossible to plan long trips with the available models of electric vehicles in India.

Industrial viewpoint:

Continental 48V hybrids:

They have introduced the fundamental principles of Mild Hybrid. and provide the data regarding daily driving range of Indian drivers.According to them, 60% of Indian drivers travel <50km daily, this means, that electric driving range of 50km is sufficient for 60-70% vehicles.

Bosch Electrification:

They have covered the technical concepts which are the core of design, implementation, research and invention of Mild hybrid vehicles. They also targeted a clear understanding of the basic technology architecture and application associated with the current and future Hybrid vehicle. and Bosch Engineering's Powertrain Department conducted a survey where they found that Indian vehicles spent 30% of their time standing in the traffic or at the signal where the engine is running at idle which results into high fuel consumption and high CO_2 emissions.

Valeo 48V hybrid electric vehicles:

They have provided the design fundamentals and the technical concepts of the 48v Mild Hybrid Vehicle.

From a literature survey it is concluded that the subject of Mild Hybrid Vehicle is gaining more and more popularity in India due to various challenges for adapting Evs and Indians city conditions.Thus MHEV is the best option for India till full electrification of vehicles.

1.3 Motivation

In India there are a lot of challenges with electric vehicles such as Lack of EV charging infrastructure, initial cost of owning, Lack of choice of EVs & Lack of Lithium reserves for battery manufacture. The Indian Government has taken on an ambitious goal of making 30% of vehicles in India electric by 2030. The switch to electric vehicles in India is happening at a rapid pace aiding the better future of electric vehicles in India. so, by 2030 Hybrid electric is the best option for the Indian environment. It will reduce the dependency on oil imports. 87% of India's automotive fuel is imported from other countries.

Due to the higher cost of EV technology, the price tag of electric vehicles in India can be a big turn-off. The cost of owning a conventional vehicle is around 5-6 Lakhs but the minimum cost electric vehicle in India is around 14 lacs, which is too high for the Indian middle-class majority. The 2x price of electric cars in the Indian economy can be a major challenge for EV companies to tackle. As per reports, the increase in price is due to the import of a lot of parts and components in electric vehicles, which is a major challenge for electric vehicles in India. As Hybrid vehicles are more fuel efficiency and provide boasting mileage with less emission in slightly higher cost than the conventional vehicle so the development in Hybrid vehicles is also important.

Objective of Project

As Growing Demand for Fuel Efficiency, Vehicle Electrification: Key Factors Impacting Accelerating Mild Hybrid Vehicles Market:

1. Brings 70% of the benefits of a full hybrid at 30% of the cost to both gasoline and diesel vehicles.
2. Four times the power of 12V, safer than full hybrids (<60V lethal threshold), less expensive electrical components.
3. Auxiliary components can be electrified to reduce power load on the engine.
4. 48 Volt electrification is driven by CO_2 and emission reduction regulations.
5. Less integration effort, weight & cost, compared to EVs systems.
6. Fast and comfortable engine start.

Chapter 2

Mild Hybrid Vehicle Modelling:

The hybrid vehicle modelled in this project was based on the specifications of the Volkswagen polo. The actual engineering data of the Insight was obtained from the official site of Volkswagen, so it was decided to use that data for testing.

2.1 Types of Mild Hybrid vehicle:

2.1.1 Series Hybrid:

In the series hybrid system, the IC engine drives the generator, and electricity is supplied to the battery. The electrical energy from the battery is then received by the motor, which in turn drives the wheels to propel the vehicle. Figure 1 illustrates the system configuration of a series hybrid electric vehicle.

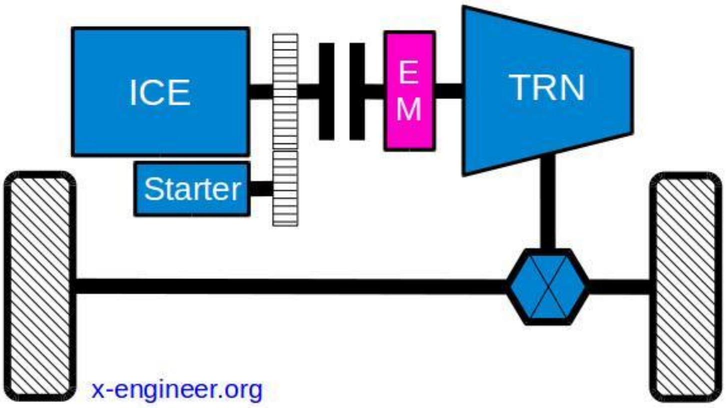


Figure 2.1.1: Schematic of a Series Hybrid Electric Vehicle

The advantage of the series hybrid is that the engine runs at its best efficiency, thus generating the maximum electrical energy to charge the battery. Since the engine is constantly operating at its optimum efficiency, and the vehicle receives its power solely from the electric motor, this system is5 most efficient during the stop and go of city driving. In addition, the internal combustion engine of the series hybrid vehicle can be replaced by a fuel cell, thus converting it into a pure electric vehicle. The disadvantage of a series hybrid vehicle is that the efficiency of the system is reduced during highway driving cycles. During highway driving, the engine has to convert fuel energy to electrical energy, which will be converted again to kinetic energy to drive the wheels. Energy losses during conversion in addition to lower torque output of the electric motor at high rotational speeds contributes to the overall lower efficiency of the system.

2.1.2 Parallel Hybrid:

The parallel hybrid configuration switches between the two power sources, the internal combustion engine and the electric motor drive, where the high efficiency range of each is selected and utilized. Depending on the situation, both power sources can also be used simultaneously to achieve the maximum power output. Figure 2 shows the system configuration of a parallel hybrid electric vehicle.

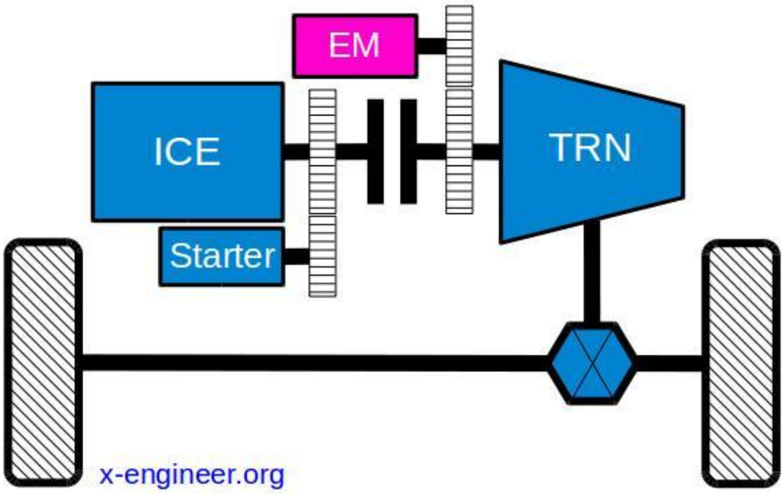


Figure 2.1.2: Schematic of a Parallel Hybrid Electric Vehicle

The advantage of a parallel hybrid vehicle is that the system has the ability to offer higher efficiency during highway driving conditions. During highway driving, the vehicle speed does not vary significantly and therefore it is more efficient to drive the wheels directly from the IC engine. In addition, the electric motor can be used solely during city driving while the IC engine recharges the battery, thus providing higher overall efficiency. In addition, both power sources can be utilized simultaneously to provide maximum performance of the vehicle.

Presently, two types of hybrid configurations have been proposed and utilized by various manufacturers: Series and Parallel Hybrid. The series hybrid consists of a fuel converter that drives the generator, in which electricity is supplied to the battery and the motor, which subsequently drives the wheels. The parallel hybrid, on the other hand, switches between the two power sources, the fuel converter and the electric motor drive, where the high efficiency range of each is selected and utilized.

2.2 Block Diagram of Mild Hybrid Vehicle:

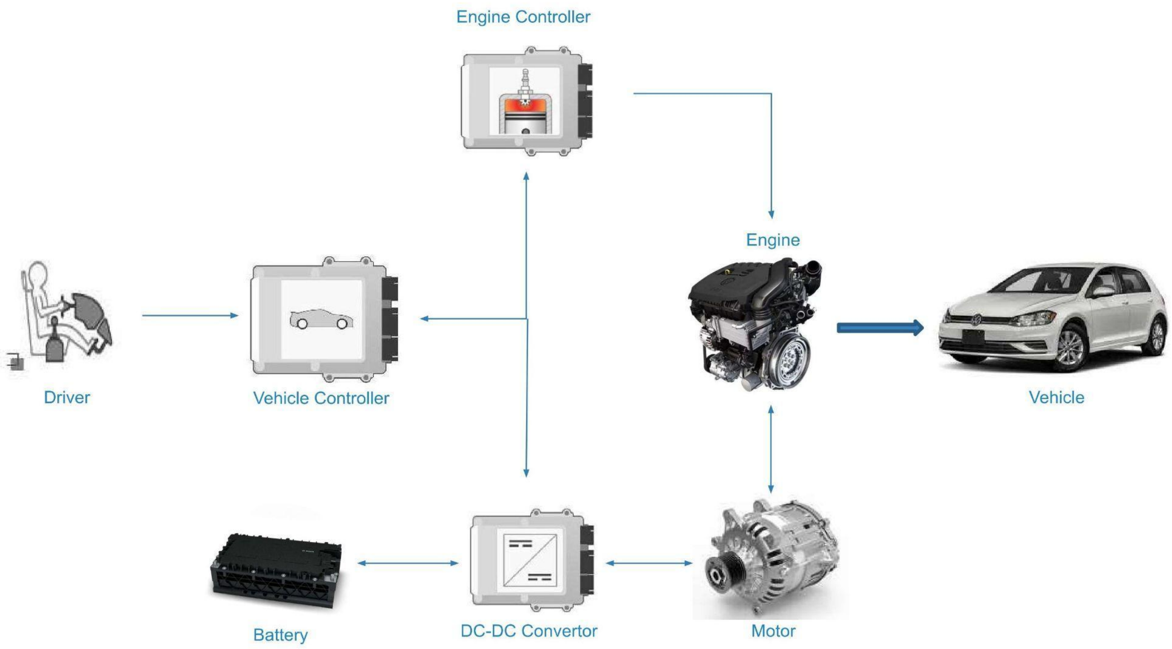


Figure 2.2.1 : Block Diagram of Mild Hybrid Vehicle

1. **Driver**: The driver gives the input via accelerator pedal to move the vehicle, and via brake pedal to stop the vehicle.
2. **Vehicle Controller**: The given driver inputs are processed by the vehicle controller and appropriate signals are given to the Engine Controller and DC-DC Convertor.
3. **Engine Controlle**r: The engine controller precisely controls the engine parameters to run the engine safely and efficiently.
4. **Engine**: It is the main power source which manoeuvres the vehicle.
5. **Battery**: The power source for the motor and storage for the electrical energy.
6. **DC-DC Convertor**: It converts the battery power to the required motor power and
7. Precisely controls the motor during motoring and regenerating.
8. **Motor**: It is the secondary power source which assists the engine and it also recaptures the breaking energy lost via regenerative braking.
9. **Vehicle**: All the above components are situated in the vehicle including the driver.

2.3 Powertrain Components:

In a vehicle, the term powertrain describes the main components that generate power and deliver it to the road surface. This includes the engine, transmission, drive shafts, and the final drive.

2.3.1 Engine:

The engine used in the model is Volkswagen Polo insight 1.0L TSI Petrol. Several characteristics of the engine such as Maximum Torque, Closed Throttle Torque, and Fuel Consumption Rate are modelled in the engine controller as lookup tables. Desired speed and Desired Torque are the input to the engine in the model by the engine controller. Which are used to operate the engine efficiently.

Engine Specifications:

1 Engine Type - 1.0L TSI petrol
2. Displacement - 999cc
3. Max Power -108.62bhp@5000-5500rpm
4. Max Torque - 175nm@1750-4000rpm
5. No. of cylinder - 3
6. Transmission type - Automatic
7. Mileage (ARAI) - 16.47

2.3.2 Motor:

The motor utilised in the project is 20KW 48V (AC) Permanent-magnet synchronous motor (PMSM).Similar to the engine, the motor is modelled using lookup tables, where the maximum torque of the motor is indexed by the shaft speed. Since the motor shaft is coupled directly to the engine crankshaft, the speeds of the motor and engine are equal at any given time.

Permanent-magnet synchronous motor with integrated inverter has three main function:

1. Provide torque to the powertrain in motor mode.
2. Convert the direct current (DC) supplied by the battery in AC, to power the electric machine when it's in motor mode.
3. Convert the AC generated by the electric machine (in generator mode) to DC, which can be stored in the battery.

Motor/Inverter specification:

Power: 20KW
Torque: 50 Nm

2.3.3 Transmission:

The transmission used in the model is Continuously Variable Transmission. It has a gear ratio that can be varied continuously within a certain range, thus providing an indefinite of gear ratios. This continuous variation allows for the matching of virtually any engine speed and torque to any wheel speed and torque. It is therefore possible to achieve an ideal torque–speed profile (constant power profile) because any engine power output to the transmission can be applied at any speed to the wheels. The commonly used CVT in automobiles uses a pulley and belt assembly. One pulley is connected to the engine shaft, while the other is connected to the output shaft. The belt links the two pulleys. The distance between the two half pulleys can be varied, thus varying the effective diameter on which the belt grips. The transmission ratio is a function of the two effective diameters

For model push belt CVT is used and control of gear ratio is by external control with the use of input primary and secondary pulley positions. Signal of input torque to the transmission provided by the engine controller. The input torque to the transmission is the sum of the engine and the motor torque, and the output torque is applied to the wheels.

2.3.4 Battery System:

Battery used in the model is a Lithium Ion battery implemented by use of a datasheet battery block. Several parameters of the battery such as internal resistance, battery temperature breakpoints, open circuit voltage, and operating temperature are parameterized in the model by datasheet provided by the manufacturer. The battery provides power to the motor as per motor requirement through DC-DC converter. The maximum energy capacity of the battery is calculated by multiplying the rated capacity and the rated voltage of the Insight s battery.

Reason behind to choose Lithium ion battery is because it is maintenance free, Compared to Lead acid and SMF: Lithium battery has 2,000 cyclic life which translates in 10 years useable life and the weight of a lithium battery is 1/4th of Other comparable batteries such as SMF, lead acid batteries

Battery specification:

1. Battery capacity: 500-Watt Hour
2. Battery rating: 48 volt
3. Technology: Lithium Ion.
4. Cycle time: More than 2000 times
5. Self-discharge rate: 6% per month @ 25˚C

2.4 Mechanical Components:

The mechanical components of the vehicle system includes vehicle chassis, suspension, driveline, steering linkages and control are implemented in the model by use of The Vehicle Body one degree-of-freedom (1 DOF) Longitudinal block. It is rigid vehicle body with constant mass undergoing longitudinal (that is, forward and reverse) motion. The vehicle body utilized in this model is a simple 4x2 Front Wheel Drive (FWD) vehicle with suspensions for both front and rear axles. The Brake and tyre of vehicle are implemented by use of longitudinal wheel block with Disc brake. Brake that converts the brake cylinder pressure into a braking force. Block provides the torque and power requirements for a specified drive cycle or braking event.

Operating Environment:

In reality, various factors of the environment such as road grade, surface condition, and wind forces would affect the vehicle's overall operating efficiency. For the sake of simplicity and consistency in order to study the efficiency of the hybrid vehicle, the vehicle is assumed to be operating in a perfect environment with air temperature 312K, where the road is assumed to be flat and sloped with a friction coefficient of 1. In addition, it is assumed that there is no additional wind force affecting the vehicle except for the drag force due to the velocity of the vehicle. The drag coefficient of the vehicle is assumed to be 0.30.

Chapter 3

SOFTWARE IMPLEMENTATION:

The hybrid vehicle model utilizes simulation software packages: MATLAB/Simulink. Here describes the software modelling in detail.

3.1 Simulink Model:

The powertrain components and mechanical components are modelled in MATLAB/Simulink R2020a operating on Windows 10. Figure 3.1 describes the overall structure of the MATLAB/Simulink model.

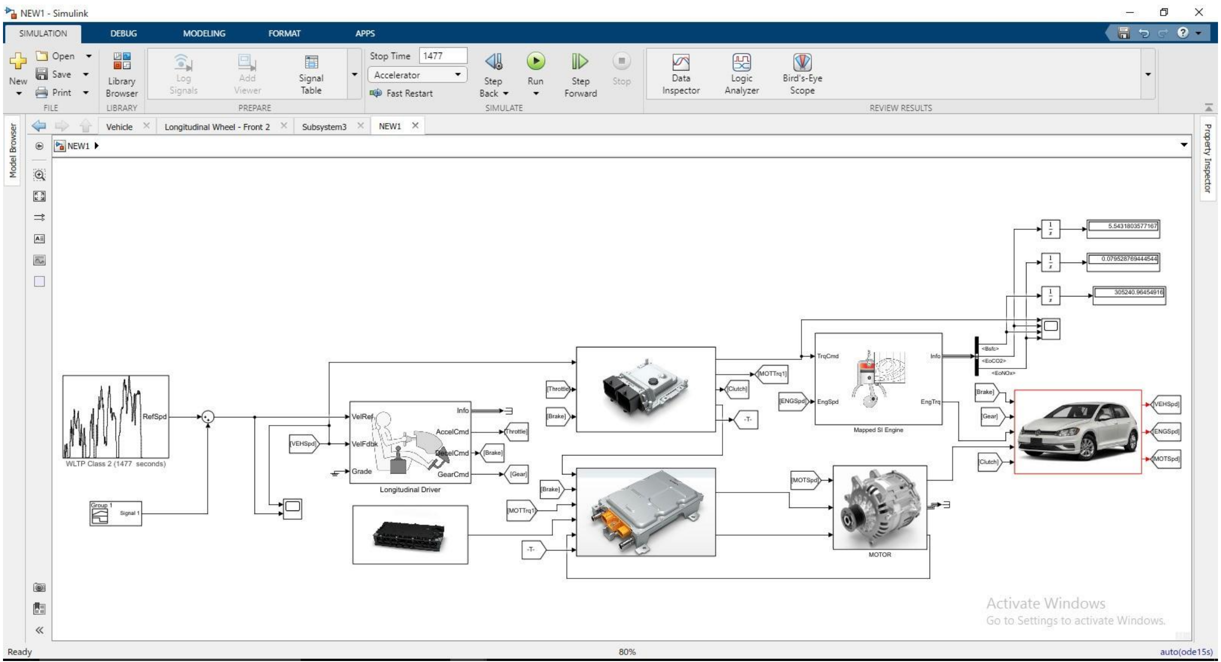


Figure 3.1: Overall Model Structure in Simulink

The MATLAB model components are set up in the chronological order of data flow starting from the left with the drive cycle data, ending to the right with the vehicle model subsystem. Input data ports of each component block are on the left hand side of the block, while the output data ports are placed on the right of each block. The output data ports are then connected to the input ports of the appropriate component block. This section will present each of the data blocks in detail.

3.2 Drive Cycle:

The drive cycle subsystem contains the time history data for the desired vehicle speed, where several standard drive cycles are modelled as look-up tables. The block outputs the desired vehicle speed based on the current simulation time. For model, WLTP class 2 drive cycle is used. Class 2 is representative of low power vehicles driven in India, Japan and Europe.

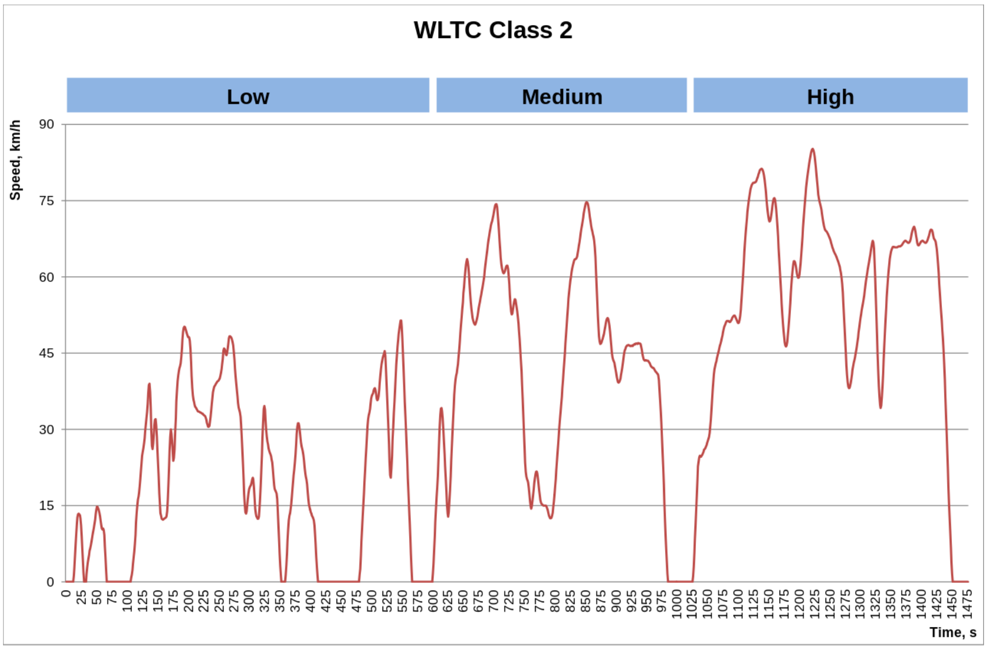


Figure 3.2: Standard WLTP Drive Cycle Class 2

3.3 Driver Control:

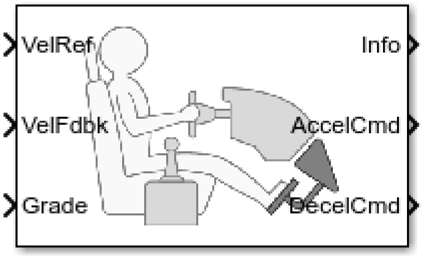


Figure 3.3: Longitudinal Driver

The purpose of the driver control subsystem is to mimic the driver's response in controlling the vehicle. A simple closed-loop proportional integral controller is used to simulate the percent throttle and the percent braking to the vehicle system. Figure 5 illustrates the driver controller. The input to the driver controller is the desired drive cycle speed and the actual vehicle speed. The outputs of the controller are percent throttle, percent braking, and the velocity difference.

3.4 Vehicle controller:

In vehicle controller an algorithm is designed with help of logic gates and if & else expression to provide signal to the Engine controller and DC-DC converter. The controller takes input from the longitudinal driver of throttle position and braking. And as per throttle position and brake parameter controller provide signal, whether to run engine alone or start motor for assistance. If the engine runs in an inefficient region it provides a signal DC-DC converter to start the motor.

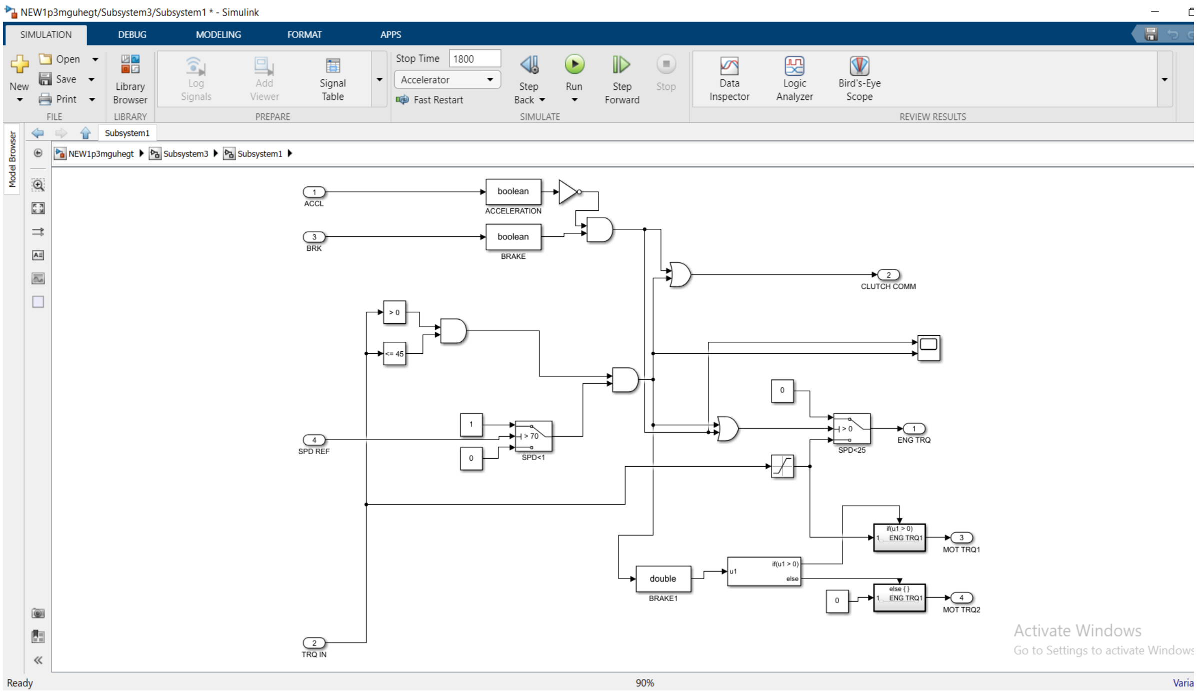


Figure 3.4: Vehicle Control Unit

3.5 Engine controller:

In model a spark ignition engine is used.it is an internal combustion engine, generally a petrol engine, where the combustion process of the air-fuel mixture is ignited by a spark from a spark plug. Hence the controller used in the model is SI controller. Controller uses the driver torque request in conjunction with measured engine speed to calculate the open-loop air, fuel, spark, and cam-phaser actuator commands required to meet the driver torque demand.

The vehicle controller manipulates engine controller parameters to run the engine safely and efficiently. The engine controller precisely controls that manipulated engine parameter. The air-fuel ratio (AFR) impacts conversion efficiency, torque production, and combustion temperature. The engine controller manages AFR by commanding injector pulse-width from a desired relative AFR. The relative AFR (λ), is the ratio between the commanded AFR and the stoichiometric AFR (14.7:1) of the fuel. If $\lambda = 1.0$ is at stoichiometry, rich mixtures $\lambda < 1.0$, and lean mixtures $\lambda > 1.0$ and to maintain idle speed if commanded torque is below a threshold value(50Nm), the idle speed controller regulates the engine speed. The idle speed controller uses a discrete PI controller to regulate the target idle speed by commanding a torque.

Provide output of Throttle area percent command, Fuel injector pulse-width, Intake and exhaust cam phaser angle to the SI engine.

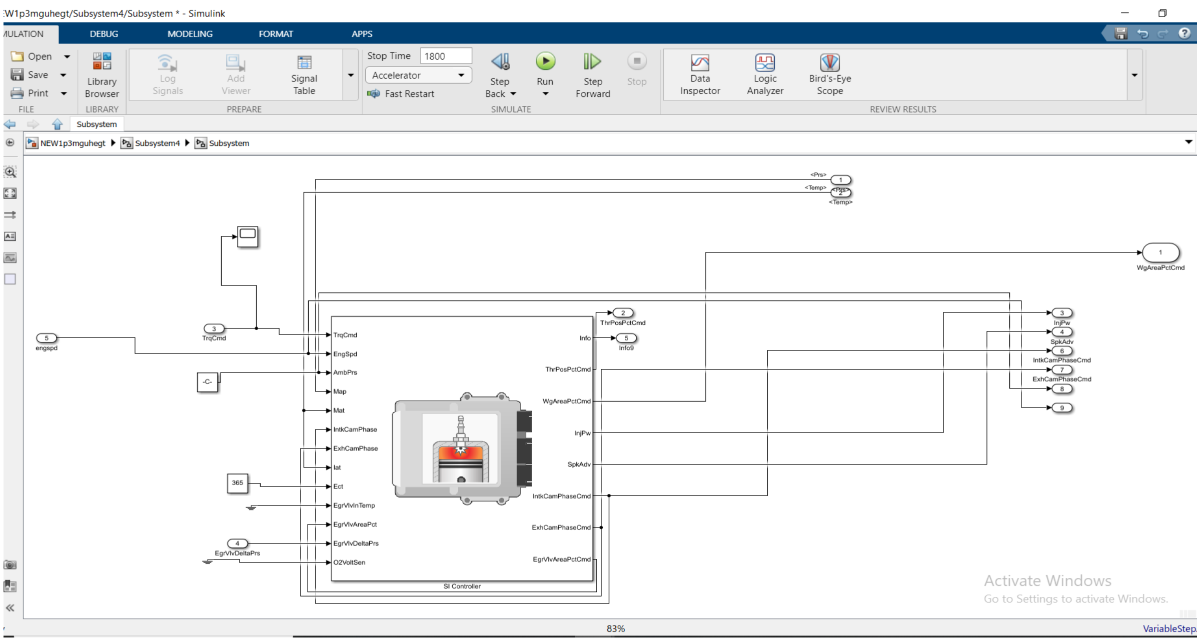


Figure 3.5: Engine Controller

3.6 Motor Controller:

Similar to the engine model, the motor output torque is modelled using look-up tables indexed by the shaft speed. Since the motor shaft is coupled with the engine shaft, the shaft speed of the motor equals that of the engine. So to control motor torque the motor controller is implemented with the help of if & else expression. A bidirectional DC-DC converter is used to step up or step down DC voltage from either side of the converter to the other as driven by an if & else expression. And also used for switching between energy storage and supply.

The if-else expression decides whether the motor subsystem performs as a motor or as a generator. During motor assist mode, the motor mode signal becomes 1. The power output of the motor is decided by the required power calculation which is performed by required torque. During the regenerative braking mode, the converter switch to generator mode and stores braking energy to the battery. Braking torque is the product of the maximum available braking torque of the generator and the percent braking from the driver.

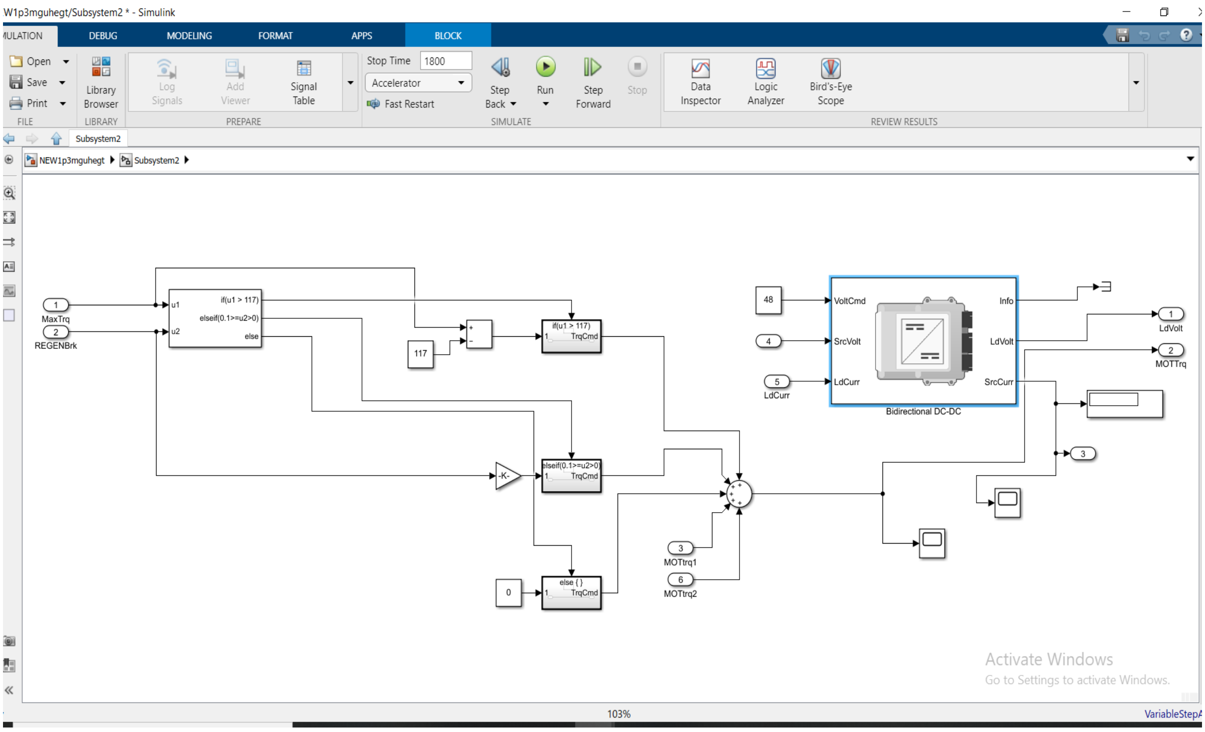


Figure 3.6: Motor Controller

3.7 Transmission:

The transmission utilised in the model is Continuously Variable Transmission. Simple logic is used to gear shifting by changing gear ratio. It has a gear ratio that can be varied continuously within a certain range, thus providing an indefinite of gear ratios by use of CVT pulley ratio request.

Here CVT controller provide output of Direction request, (controlling the direction, either forward or reverse),primary pulley displacement and secondary pulley displacement to control the gear ratio in The Continuously Variable Transmission block with respect to the required Engine torque. CVT provides output of Input & output drive shaft angular speed to the wheel and brake subsystem and then to the vehicle longitudinal block. Unit converter used to check engine speed.

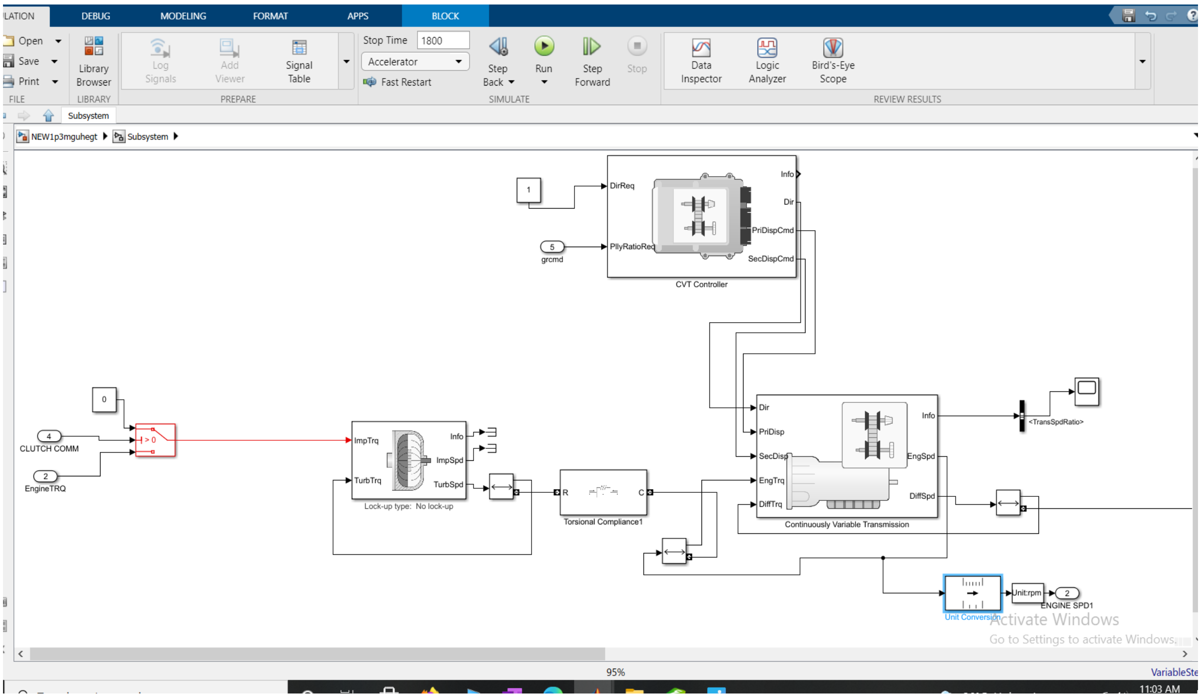


Figure 3.7: Transmission subsystem

Chapter 4:

SIMULATION RESULTS

The purpose of a hybrid vehicle is to provide better fuel efficiency over a conventional vehicle.it is essential to show that the hybrid vehicle model indeed provides better fuel efficiency over a conventional vehicle. The purpose of this topic is to provide an efficiency performance comparison of the MATLAB hybrid vehicle over a conventional vehicle.

The conventional vehicle model will be based on the same hybrid vehicle model developed for this thesis, but without the motor assist and the regenerative braking. The vehicle performance of the hybrid and the conventional vehicle models will be compared over the same standard drive cycles. Standard WLTP Class2 (Emission Test cycle) drive cycles will be used to simulate city driving.

4.1 Emission Test Cycle (WLTP2):

As previously mentioned, the Emission Test Cycle is used to simulate city driving. Figure 4.1 depicts that the MHEV is precisely following the WLTP-2 drive cycle. The MHEV is following the reference speed of the drive cycle.

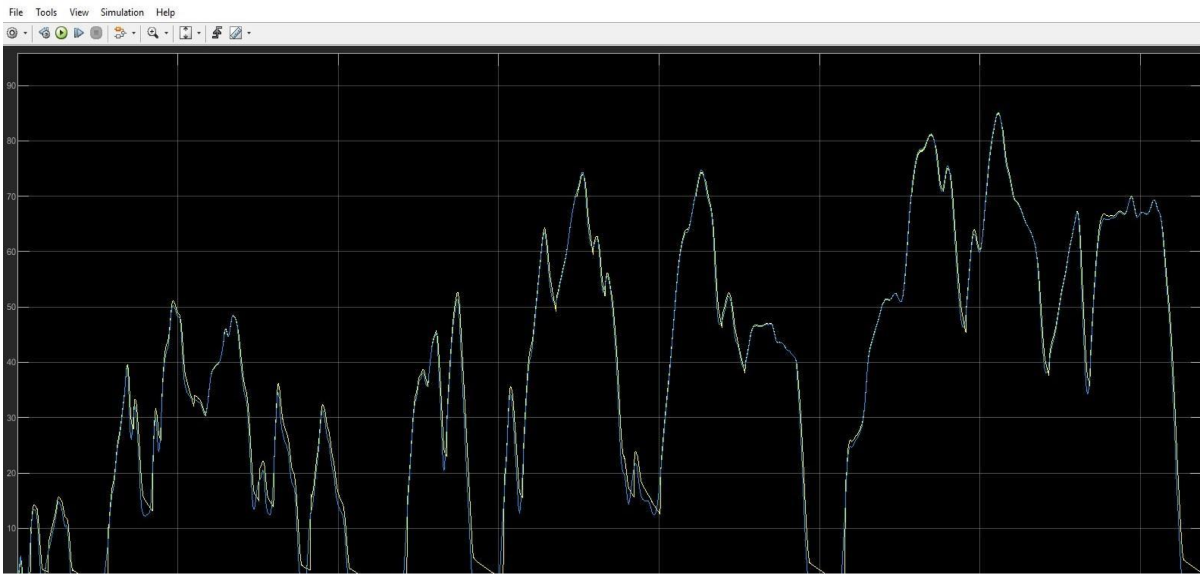
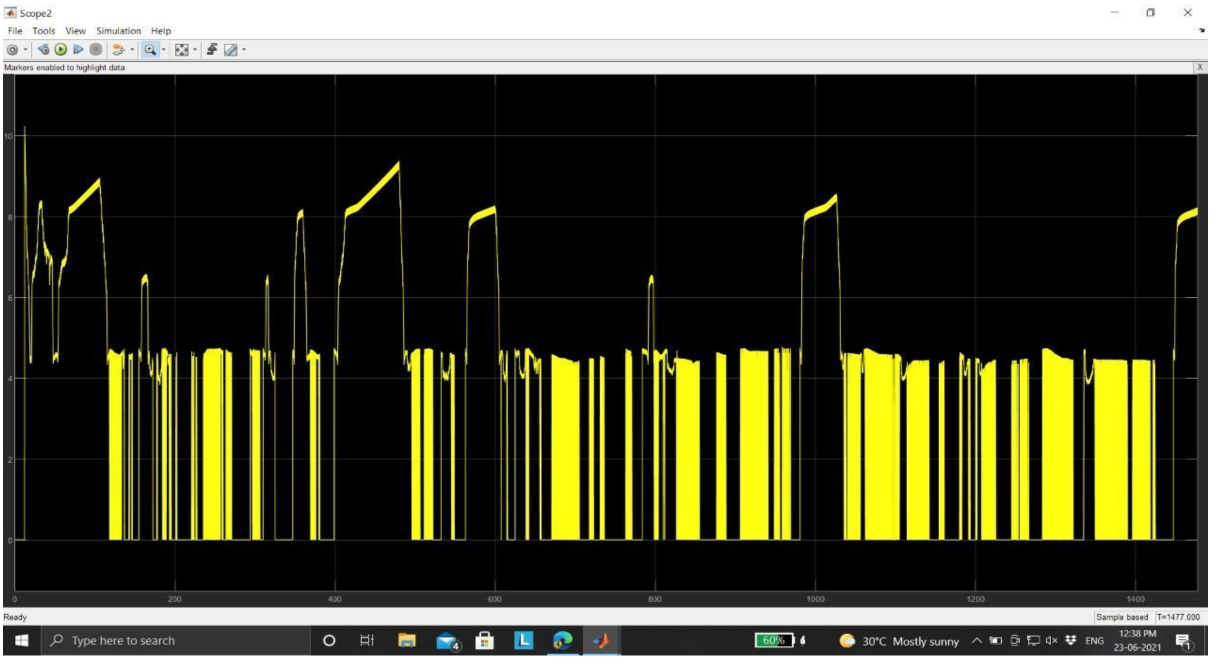


Figure 4.1: WLTP-2 Drive cycle test on the MHEV

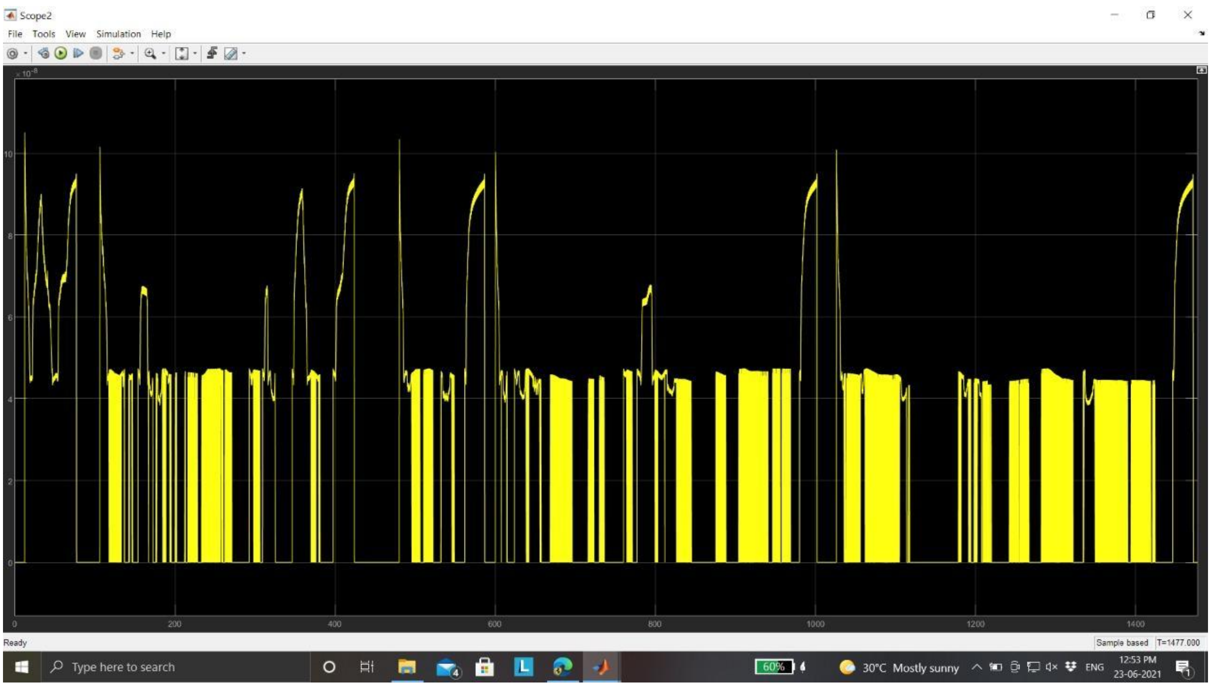
4.2 Fuel Consumption Comparison:

To demonstrate the advantages of a hybrid vehicle over a conventional vehicle, it is essential to analyse the fuel consumptions of the vehicle. In order for the vehicle to achieve the desired speed profile, the driver logic applies the appropriate percent throttle and braking accordingly. Since the conventional vehicle model does not utilize motor assist and regenerative braking, only the engine torque and the mechanical brakes are available throughout the drive cycle.

Figure **4.2 &4.3** depicts fuel consumption of conventional and hybrid vehicles respectively.



4.2: Fuel consumption of the conventional vehicle.



4.3: Fuel consumption of the MHEV.

As expected, the total amount of fuel consumed by the MHEV is lower than that of the conventional vehicle. The conventional vehicle model used engine in the inefficient zones than the hybrid vehicle model, which is logical since the conventional vehicle does not have the additional motor torque of the hybrid vehicle, and thus, the fuel consumption is more.

4.3 Motor Operation:

Figure 4.4 illustrates Motor operation of the hybrid vehicle throughout the drive cycle. Due to the stop and go nature of city driving, the regenerative braking of the hybrid vehicle was able to recover the kinetic energy, which would otherwise be lost to the mechanical brakes, back into electrical energy to recharge the battery. The recovered electrical energy can then be used to provide additional power to the motor during the assist mode, and further reduce the amount of fuel consumed. The process of recovering lost kinetic energy into electrical energy for later use is essentially the major advantage of a hybrid vehicle over a conventional vehicle.

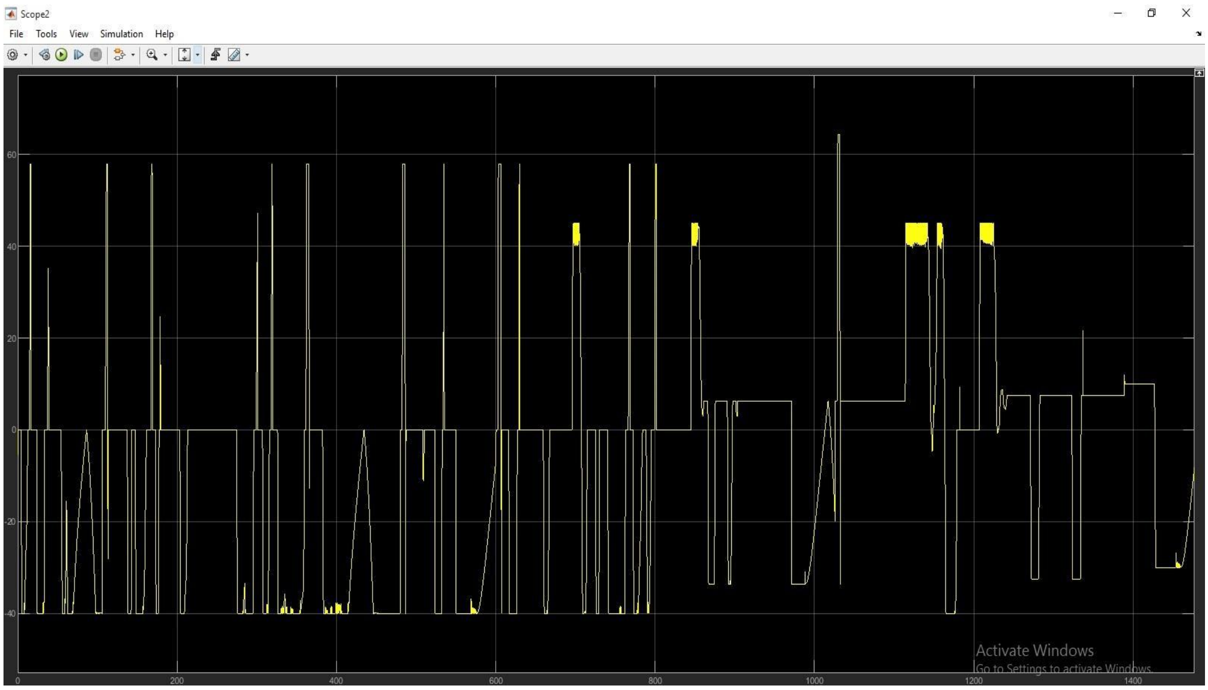


Figure 4.4: Motor Operation

4.4 Emission Comparison:

As conventional vehicle do not have the additional motor torque of the hybrid vehicle, and thus additional engine torque is required for the vehicle to achieve the desired speed, the conventional vehicle model applied more throttle than the hybrid vehicle model, this will increase the emission of conventional vehicles.

Figure **4.5 & 4.6** illustrate the emission of conventional and hybrid vehicles respectively.

4.5: Emissions of the conventional vehicle.

4.6: Emissions of the MHEV

Above result shows that the MHEV produced up to **25% less emissions.**

The final result obtained from the WLTP-2 drive cycle are:

- ☐ **9.6841%** more fuel economy.
- ☐ **11.0017%** less NOx emissions.
- ☐ **4.9393%** less CO2 emissions.
- ☐ **4.8543%** less CO emissions.
- ☐ **4.7765%** less hydrocarbon.

Chapter 5

CONCLUSION AND FUTURE SCOPE:

5.1 Conclusion:

The SIMULINK hybrid vehicle model was successfully created based on the Parallel hybrid architecture. The energy components and the vehicle controllers were created in Simulink. The powertrain components utilized in the hybrid vehicle model were based on the Volkswagen POLO 1.0L TSI engine and the 20KW AC Permanent magnet synchronous motor.

In order to demonstrate the fuel efficiency advantages of the hybrid vehicle over the conventional vehicle, a comparison study was performed over standard city cycle. The WLTP-2 standard simulations were performed on the hybrid and the conventional vehicle models. The hybrid vehicle model demonstrated 9.68% fuel economy improvement over the conventional vehicle model for the WLTP-2 drive cycles. In addition, due to the stop and go nature of city driving, it was demonstrated that the regenerative braking recovered sufficient kinetic energy to recharge the battery for motor assist. and also demonstrated 25% less emissions than the conventional vehicle.

The SIMULINK hybrid vehicle model offers a simulation platform that is modular, flexible, and can be easily modified for different types of vehicle model. In addition, the simulation results clearly demonstrated the fuel economy advantage of the hybrid vehicle over the conventional vehicle.

5.2 Future scope:

The engine can be utilised in a more efficient by applying technologies such as EGR (Exhaust gas recirculation) and VLIR (Variable Length Intake Runner) which will increase fuel economy and decrease emissions.Current power management utilizes a simple motor assist and regenerative braking logic, it is recommended that a more sophisticated power management controller be implemented to optimize the efficiencies of the engine and the motor.

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