Contents

Chapter *1*

Hybrid Electric Vehicles

History

The first patent filed for a gasoline-electric hybrid vehicle system by William H. Patton was in early 1889 and for a similar hybrid boat propulsion system in mid 1889. A prototype was built in 1889 and an experimental tram car was run in Pullman, Illinois in 1891. In 1905, Henri Pieper of Germany/Belgium introduced a hybrid vehicle with an electric motor/generator, batteries, and a small gasoline engine. It used the electric motor to charge its batteries at cruise speed and used both motors to accelerate or climb a hill. In the first half of 20th century there was not much development in Hybrid Electric vehicles (HEVs) but HEVs started to resurge in 1960s, The regenerative braking system, a core design concept of most modern production HEVs, was developed in 1967 for the American Motors Amitron and called Energy Regeneration Brake by AMC. A more recent working prototype of the HEV was built by Victor Wouk his work with HEVs in the 1960s and 1970s earned him the title as the "Godfather of the Hybrid". Research and Development was advancing in the 1990s with projects such as the early BMW 5 Series a CVT hybrid-electric vehicle. In 1992, Volvo ECC was developed by Volvo. This used gas in place of gasoline to assist the motor drive. Automotive hybrid technology became widespread beginning in the late 1990s. The first mass-produced hybrid vehicle was the Toyota Prius, launched in Japan in 1997, and followed by the Honda Insight, launched in 1999 in the United States and Japan. The Honda Insight using a mild parallel hybrid system and Toyota pirus with series-parallel hybrid architecture typify the two modern schools of thought regarding passenger hybrid vehicle. These vehicles have high part interchangeability with their conventional siblings and deliver the benefits of hybridization without high costs [1]. The Mercedes-Benz S400 BlueHybrid was unveiled in 2009 it is a mild hybrid and the first hybrid to use lithium ion batteries. The Peugeot 3008 HYbrid4 was launched in the European market in 2012, becoming the world's first production diesel-electric hybrid. According to Peugeot the new hybrid delivers a fuel economy of up to 62 miles per US gallon (3.8 L/100 km) and CO_2 emissions of 99g/km on the European test cycle. The sales of HEVs is also increasing in the recent years as of January 2017, more than 12 million HEVs have been sold worldwide since their inception in 1997. As of April 2016, Japan ranked as the market leader with more than 5 million hybrids sold, followed by the United States with cumulative sales of over 4 million units since 1999[2].

Introduction

Environmental as well as economical issues provide a compelling impetus to develop clean, efficient, and sustainable vehicles for urban transportation. Automobiles constitute an integral part of our everyday life, yet the exhaust emissions of conventional internal combustion (IC) engine vehicles are to blame for the major source of urban pollution that causes the greenhouse effect leading to global warming [3]. Besides air pollution, the other main objection regarding ICE automobiles is their extremely low efficiency use of fossil fuel. Hence, the problem associated with ICE automobiles is threefold: environmental, economical, as well as political. Electric vehicles and HEVs offer the most promising solutions to reduce vehicular emissions. EVs constitute the only commonly known group of automobiles that qualify as zero emission vehicles. These vehicles use an electric motor for propulsion and batteries as electrical-energy storage devices. Although there have been significant advancements in motors, power electronics, microelectronics, and microprocessor control of motor drives, the advancement in battery technology has been relatively sluggish. Hence, the handicap of short range associated with EVs still remains. Given these technology limitations, the HEV seems to be the viable alternative to the ICE automobile at the present. HEVs qualify as the ultra low emission vehicles and do not suffer from the range limitations imposed by EVs [4].

The term “Hybrid Electric Vehicle” generally refers to vehicles that use an IC engine in conjunction with one or more electric machines for propulsion. The definition of HEVs is proposed by the technical committee 69 of Electric road vehicles of the International Electro technical commission. The traction electric motor can be operated independently or association with ICE to power the wheels of the vehicle depending on the type of vehicle architecture which depends on the requirements of vehicle. The vehicle design complexity increases significantly for hybrid vehicles, since control system are to be defined for both ICE and electric machines in addition to the component design for controlled blending of power from two sources.

Converting a conventional car powered by internal combustion engine (ICE) into a HEV is one of the methods employed in the development of a HEV. This type of HEVs are developed based on the modification from existing conventional car, where the modified conventional vehicle cum HEV has an additional propulsion system that can either assist or propel the vehicle. Some examples of this technology are the Poulsen Hybrid Power Assist System, the REVOLO, and MIRA’s H4V Plug-in Hybrid. By having a HEV model built from a conventional vehicle, it is expected that the HEV model would have the same driving characteristic as the base model. In addition, the HEV model would also improve the performance in term of fuel consumption and emissions. In most common practice, prior to converting the conventional car into a HEV, modeling work using commercial software is required. The vehicle model must resemble the actual vehicle as close as possible. Previous works on modelling of a converted conventional car into a HEV is very common but very few literatures can be found because most automotive manufacturers tend to keep secrets from their competitors. Therefore, due to the lack of literatures, general work related to the HEV designs and modeling is essentials for the reference/guidance of converting a conventional car into HEV. Due to the modifications imposed on the conventional car, the handling characteristics of the new modified cum HEV have changed owing to the additional masses such as batteries, controller, motors, etc. so it is suggested to keep the mass distribution ratio same on both the axles as conventional vehicle[5].

Classification of HEVs

- **Hybrid based on Architecture**

HEV can generally be classified in three types, based on the Architecture: series HEV, parallel HEV, mixed series-parallel HEV.

- Series HEVs - HEVs with a series configuration employ exclusively the electric motor for propulsion. Electrical energy is produced by an ICE-driven generator and stored in a bank of accumulators. The ICE works at constant speed in the point of maximum efficiency, allowing a dramatic reduction of emissions and acoustic noise. It has a comparatively simple drive train and is suitable for short trips.

- Parallel HEVs - In parallel HEVs the two power sources are both connected to the power train system, summing their torque and increasing the total performance. The system has also the possibility to selectively connect the motors to the transmission shaft. The two motors can compensate each other and can be undersized with respect to total vehicle power. In particular, the electric motor can be used to allow the ICE to work near the optimal conditions, for example it can deliver torque during standing starts or gear up or down. The transmission is more complex than in the case of series HEVs, but the parallel configuration is energetically more efficient due to the lower energy conversions count. It needs only two propulsion components unlike series on short trips both can be utilized and in long trips motor can assist engine to reduce fuel consumption and emissions

- Mixed series-parallel - The mixed series-parallel configuration brings a great flexibility giving designers the possibility to achieve the advantages of both architectures, but needs, with respect to series HEVs, an extra connection between the ICE and the wheels and a generator, which is absent in the parallel configuration. The electric motor can work as both motor and generator (in case of negative torque) to regenerate the energy of the batteries in each of the configurations. It is also called complex hybrid.

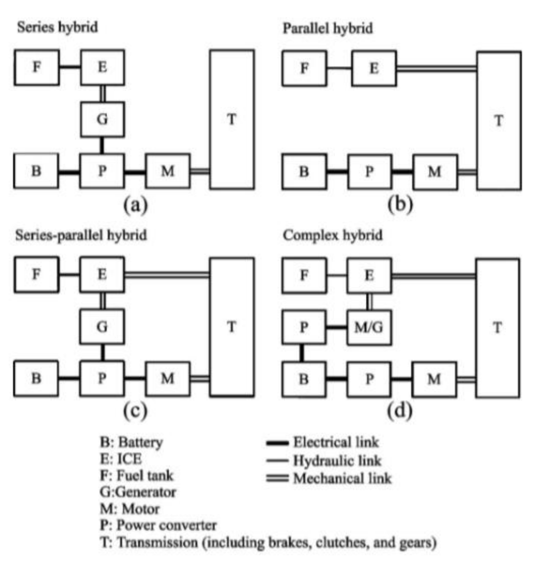


Fig1-Different types of HEV Architectures

In the work discussed a Parallel HEV configuration was used as it solves the major issue of emissions and it improves fuel consumption by 20-30% with no compromise in vehicle's performance.

- **Hybrid based on Transmission Assembly**

  HEVs can be classified as pre- and post-transmission hybrids depending on the position of mechanical transmission with respect to electric drive.

  - In the pre-transmission configuration, the output shafts of the electric motor and ICE are connected through the mechanical coupling before the mechanical transmission gearbox. The transmission matches the combined output of the electric drive and IC engine with the vehicle speed. The mechanical transmission components including the gearbox are located between the final drive and the propulsion components.

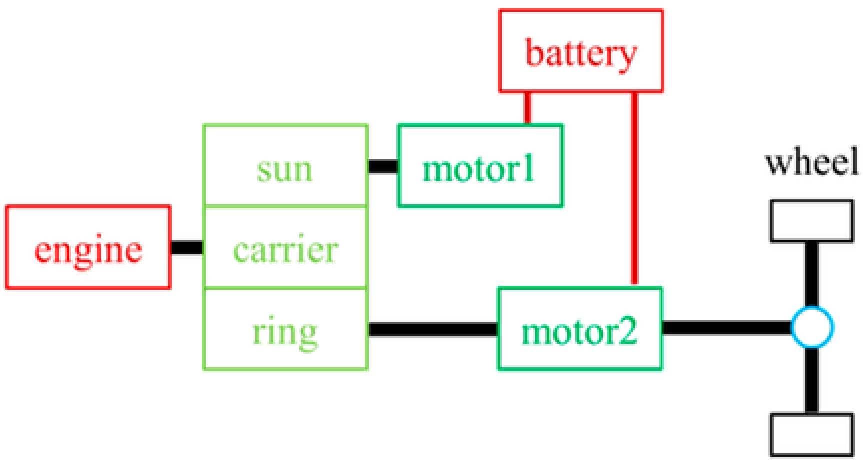


Fig2- Pre-Transmission

  - In the post-transmission hybrid configuration, the electric motor drive is coupled to the output shaft of the transmission. A gearbox may be used to match the entire speed range. Consequently, motor drives for post-transmission configurations are required to have a wide constant power speed region (CPSR).

    Hybrid vehicle with wheel or hub motors are of similar post-transmission configuration. But hub motors results in higher un-sprung mass and are also prone to higher vibrations and environmental conditions like temperature, water, sand and dust etc. As this work is based on conversion to a HEV so here a new design is proposed in which the dead axle at the rear wheels will be replaced by a live axle with differential as shown in Fig.3. Motor will provide torque in combination to engine in parallel mode but on different set of wheels (rear). This modal will convert the vehicle in a parallel hybrid as well as in four-wheel dive.

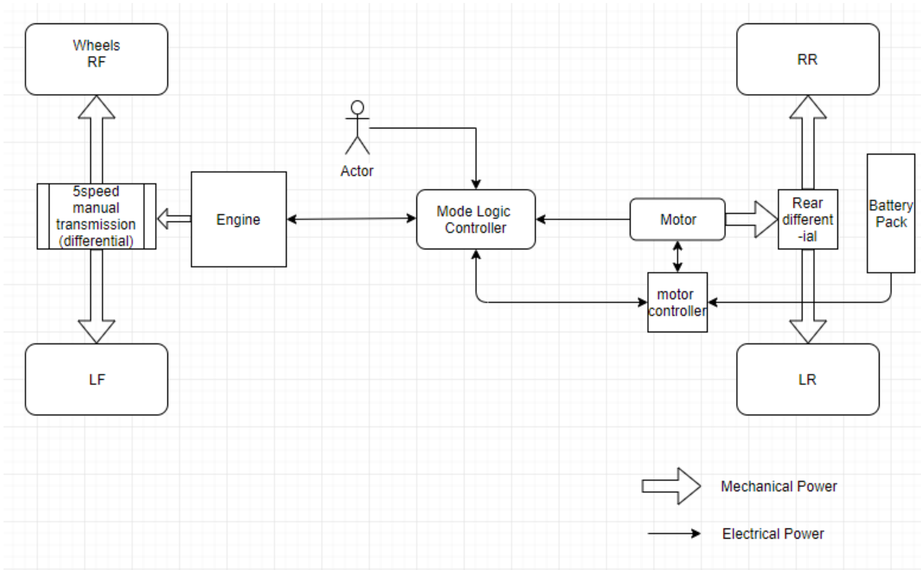


Fig3- Post-Transmission (Proposed Architecture)

- **Hybrids based on degree of hybridization**

  There are three "mission-based" classes: mild hybrids, power hybrids and energy hybrids.

  - Mild Hybrids- In this there is lowest degree of hybridizations with a moderate effect on fuel economy and emissions typical electrical rating of mild hybrid would be in the range of 5-10 kW and energy capacity in the range of 1-3kWh
  - Power Hybrids- It has a relatively larger electrical rating as high as 40kW; these allow significant amount of power transmission between battery and motor drive system. The power hybrids have greater potential to minimize fuel consumptions and have better engine out emissions due to more focused engine duty cycle.
  - Energy Hybrids- It employs a high energy battery system capable of propelling the vehicle to a significant range without engine operations. The electrical rating and battery capacity are in the ranges of 70-100kW and 15-20 kWh respectively.

In this case we have considered Mild hybrid as the main focus here is on reducing the fuel consumption and emissions.

Chapter *2*

Litrature Survey

Model-Based Design for HEV Systems

Many researchers have worked in the field of development of hybrid electric vehicle based on Matlab Simulink modeling Butler et al.[6] did a work development of different types hybrid vehicle and then compared it to conventional fuel vehicle and electric vehicle and made observations regarding fuel consumption, emissions and battery energy consumption on four different drive cycles and found that the milage (km/l) for the parallel HEV is extremely large compared to series and conventional vehicles due to the minimal usage of the ICE in urban drive cycle as there is lot of acceleration and deceleration and there is minimum use of ICE, the battery pack is the sole power supplier in the EV so its energy usage is greater than the parallel or series hybrid vehicles, as expected. The NOx concentrations were found minimum in parallel HEV compared to series HEV and conventional vehicle but there were no emissions in EV. Mahapatra et al. [7] did a similar type of work in modeling of HEV and reported the problems faced in designing of HEV and its complications. They justified the modeling based design of the system and HEV, they also discussed the development of control logic for different drive cycles. Baruah et al.[10] discussed about the state of charge of battery and fuel consumption of HEVs and observed that during cruising conditions when the average speed of the vehicle is maintained split ratio reduces, indicating more contribution from IC engine and thereby maintaining fuel efficiency. On the other hand in the instances of fluctuating demand split ratio goes up, medium or high, depending on the intensity of fluctuation. It was concluded that use of efficient controller helps in selecting appropriate gear ratio, thereby reduces the IC engine power requirement and play an important role in achieving fuel efficiency.

Component Design of HEVs

The designing of HEV’s components is already discussed as suggested by Hussain[8] a similar type of work is also discussed by Ehsani et al.[4] and found that the design must be done to meet the operational constraints with minimum power requirement. There study concluded that the extended constant power operation is important for both the initial acceleration and cruising intervals of operation. The more the motor can operate in constant power, the less the acceleration power requirement will be. They also found that induction motor has clear advantage over BLDC and SRM motors for the EV and HEV at the present. Concari et al.[9] discussed different architecture of HEV for urban mobility different control logics were made and system level design was done for optimizing of the gear ratio and gear changing according to urban drive cycles. Pyrzak in his work explained the architecture and components used in the most sold hybrid vehicle of all time i.e. Toyota pirus he elaborate the different components of HEV drive train including power split devices.

Conversion of conventional vehicle to HEV

There are not many research works done in the conversion and simulation of conventional vehicles to HEVs Pyrzak et al. [5] discussed various problems which come in conversion of conventional vehicle to HEV. They designed the converted vehicle (Proton WAJA) in ADAMS/Car and MATLAB/Simulink The model was aimed to possess improved characteristic in term of fuel consumption and vehicle handling as compared to the base model. They initially tested the model to examine its handling characteristics through simulations and concluded that results revealed that the HEV model had improved the fuel consumption of the vehicle compared to base model. A similar type of example is discussed by Hussian [8] in which a conventional vehicle was totally converted to HEV he also changed and reduced the size of ICE and all the components were designed on MATLAB/Simulink based modeling

Research Gap

Many of the research works are done in MATLAB/Simulink based modeling of the vehicles but very little work is done in conversion of conventional vehicle to HEVs without changing the installed IC engine setup as it can improve the emissions and fuel consumption of vehicles significantly in urban drive cycle and the IC Engine present in the vehicle can still be used when long range rides are required this will also helps in reducing pollution in cities and is a great option for future when fossil fuel cost will rise significantly as they are limited, and pollution norms will get more strict so conversion is a great alternative for buying new HEVs or EVs.

Chapter *3*

Proposed Work

<u>Power-Train Design of HEV</u>

Vehicle longitudinal dynamics analysis is the core of any power-train design. The analysis of power-train on different conditions is necessary to predict vehicle's real time performance. In the work discussed, power-train is analyzed for the existing vehicle i.e. ford ikon. There are many different aspects when designing a power train including selection of drive train components, deciding proper capacity of those components, deciding the gear ratios between different components and most importantly optimizing the control logic of the vehicle in a way that it meets our performance, fuel consumption and emissions demands.

- <u>*Selection of drive-train components*</u>: The component for electric drive train was done on the basis of compatibility with the modal. It involves selection Motor, Batteries, throttle controller and differential.
  Two different types of motor viz. Brushless DC motor and AC induction motor were compared for use. Motors were compared on the basis of their constant power range and max RPM. The data of two motors is shown in the table below[Mehrdad Ehsani, Fellow, IEEE, Khwaja M. Rahman, Student Member, IEEE, and Hamid A. Toliyat, Member, IEEE].

Motor Type	Rated Speed	Maximum Speed	Constant power range
Induction	1750	8750	1:5
BLDC	4000	9000	1:2.25

Extended constant power region helps in reducing the overall power requirement of the motor and eliminates the need of transmission system. Low rated speeds helps in increasing the constant power range which can be validated from the following equations:

For this case let there is ideal condition when only road load is considered. Here the vehicle acceleration is expressed as a function of vehicle velocity and longitudinal force.

$$m \int_0^{v_{rv}} \frac{dv}{F} = \int_0^{t_f} dt.$$

Force can be expressed as a function of velocities. One thing to be noted here is that vehicle velocity is devided in two segments viz. from 0 to motor rated speed and from motor rated speed till vehicle rated speed.

$$m \int_0^{v_{rm}} \frac{dv}{\frac{P_m}{v_{rm}}} + m \int_{v_{rm}}^{v_{rv}} \frac{dv}{\frac{P_m}{v}} = t_f.$$

From the below expression it clear that on reducing motor rated speed constane power range increses.

$$P_m = \frac{m}{2t_f}\left(v_{rm}^2 + v_{rv}^2\right).$$

Another important point while designing a motor is that it must require less current as higher currents increases power loss in form of heat. The equation described below describes the motor RPM and torque behaviour.[10]

$$V_A = R_A i_A + L_{AA} + di_A/dt + e_A \qquad (4)$$

$$E_a = K\,\phi\,\omega_m \qquad (5)$$

$$T_e = K\,\phi\,i_A \qquad (6)$$

For same power and with high ω_m and low torque T_e there will be less requirement of current and hence less losses.

For the work discussed there is a requirement of high intial torque motor and as the motor is used for a very limited range of speed constant power range has not that much impact on power required so BLDC motor is selected as it provides low torque and high RPM for same power output.

Apart from motor the batteries used were Lithium Ion as it has high power density. The overall wieght of the converted vehicle must remain close conventional vehicle so that overall dynamics of the vehicle did not get effected and so Lithium ion battery is the best avilable choice.

- *Components sizing for our vehicle*: This part was covered in the last semester different power requirements were concluded according to the drive loads. In this work mild hybrid is considered so a motor of rated power 8kW is selected. The electrical attributes of the motor were taken from a motor present online and the motor is parameterizing on that basis.

- *Deciding different gear ratios in the power train*: One of the major task was calculating the correct gear ratio the vehicle(ford ikon) is having as it has a major imapct on performance of the vehicle. This was done in the AVL cruise the different gear ratios for 5-speed transmisson were put into the model made according to the literature survey. As the output performance parameters like top speed and vehicle (0-100 km/hr) acceleration were known(shown in table-3) reverse process was used to determine the gear ratio by trial and error method. The gears for which 0-100km/hr was achived in 14.5 second were finallized. The gear shifting graph while attaining max velocity is shown in fig.4. The driver behaviour is in built in AVL cruise so it was not altered. The final gears selected are shown in table 2.

Gear No.	1	2	3	4	5
Gear Ratio	2.94	1.94	1.34	1	.68

Table2- Gear ratio for different gears

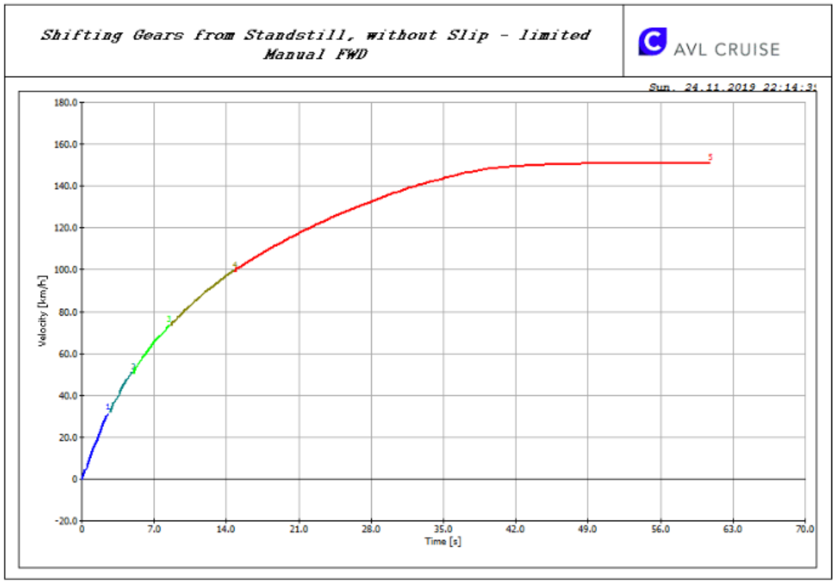


Fig.4- Gearshift when achiving max velocity from stand still

Sr. No.	Parameters	Values
1	ARAI Mileage	14.2 kmpl
2	City Mileage	10 kmpl
3	Fuel Type	Petrol
4	Engine(cc)	1597
5	Max Power	68@5500(kW@rpm)
6	Max Torque	128@2500(N-m@rpm)
7	Max RPM	6175
8	Engine Description	1.6L 92bhp 4 cyl. In-line Rocam
9	Compression Ratio	10.2:1
10	Transmission type	Manual
11	Gear Box	5 Speed
12	Synchronizers	No
13	Top Speed	157 kmph
14	Acceleration (0-100 kmph)	14.5 seconds
15	Fuel Tank Capacity (Liters)	35
16	Length	4,140 mm
17	Width	1,634 mm
18	Height	1,379 mm
19	Wheel Base	2,486 mm
20	Tyre Size	175/70 R13
21	Wheel Size	13 x 5 1/2 JJ
22	Kerb weight	1000kg
23	Wheel Radius	27 inchs
24	Air density	1.225kg/m^3
25	Drag coefficient (C_D)	.3
26	Frontal area (A_F)	1.225m^2
27	Rolling Resistance coef.(C_o)	.015
28	Head Wind(V_o)	3m/s
29	Weight with electric drive	1150kg

Table3-Vehicle specifications and operating parameters

Another gear ratio which was to be designed was for final drives of motor unit. As the motor was selected and designed the rated and maximum RPM of motor were known which are V_{rm}= 2500 and V_{max}= 9000 also the motor can supply max 8 kw of torque so the rated torque the motor can supply was coming to be 30N-m from equation 7.

$$P(kW)=2*\pi*\tau*N/60 \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

While running the model of Conventional vehicle on the same drive cycle the required values of torque at the wheels were calculated and it was coming to be 400N-m. The gear ratio for the final drive was decided from here and it was coming 13.33. As such high gear ratio is not practical so a standard gear ratio of 12 was taken. This gear ratio must be applied into two steps in practical conditions.

- <u>*Determining the control system for gear*</u> <u>shift</u>: It is an important factor while modeling the vehicle because gear shifting is very specific to the application or performance expectation like for maintaining fuel consumption the gears must be shifted at a lower RPM when a lean mixture is injected on the other hand for getting maximum acceleration gears are always shifted near to maximum RPM in yhis case that is 6175. The Gear change algorithm was designed for two cases as stated above. The velocities for getting the maximum acceleration and best fuel consumption were calculated on AVL cruise which is shown in fig.5.

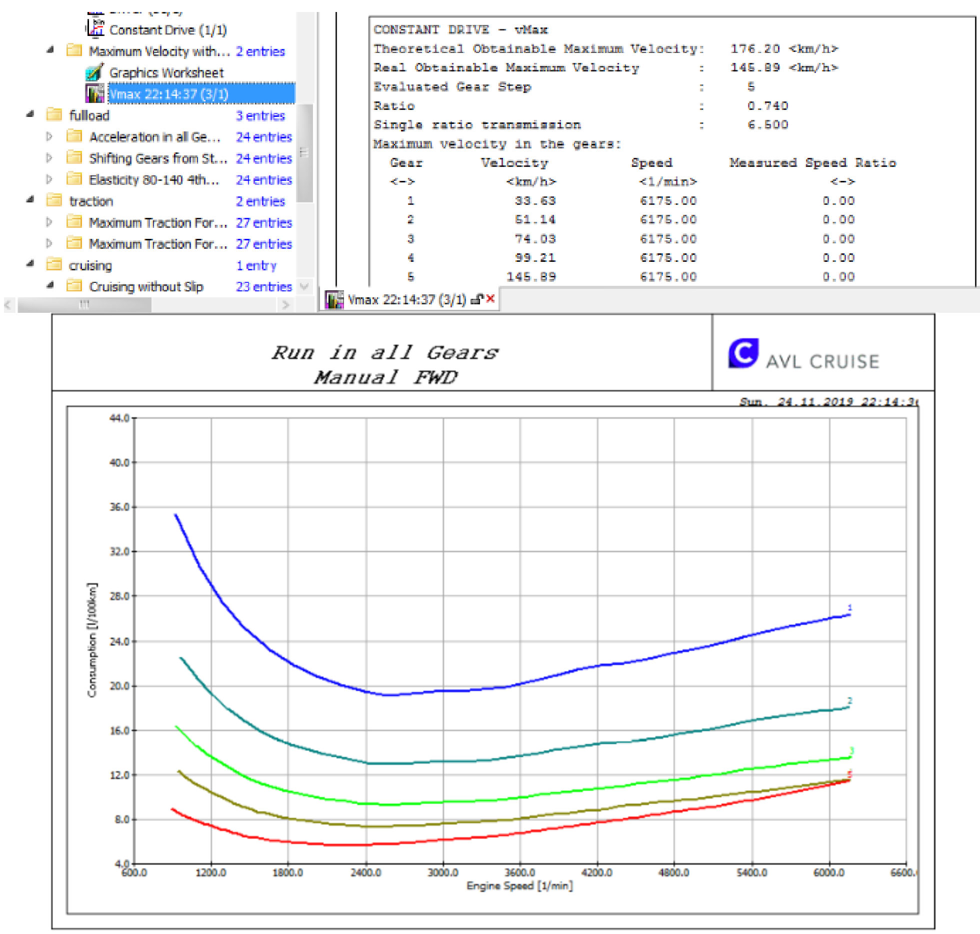


Fig. 5- Shifting Velocities for maximum acceleration and optimum fuel consumption

The optimum velocity for gear shifting was taken out by using the formula in eq (8).

$$2 * \pi * N * R_{Wheel} / 60 * GR \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \ldots\ldots\ldots\ldots\ldots\ldots \; (8)$$

Where GR is gear ratio of complete drive train.

The gear shifting velocities is mentioned in the table 4 and the mode logic was designed in the state flow chart in MATLAB/Simulink(Fig.6) by using this data.

Gear No.	1	2	3	4
Max acc.	33	61	74	99
Fuel Consumption	13.44	20.4	29.59	39.65

Table 4- Gear shifting velocities

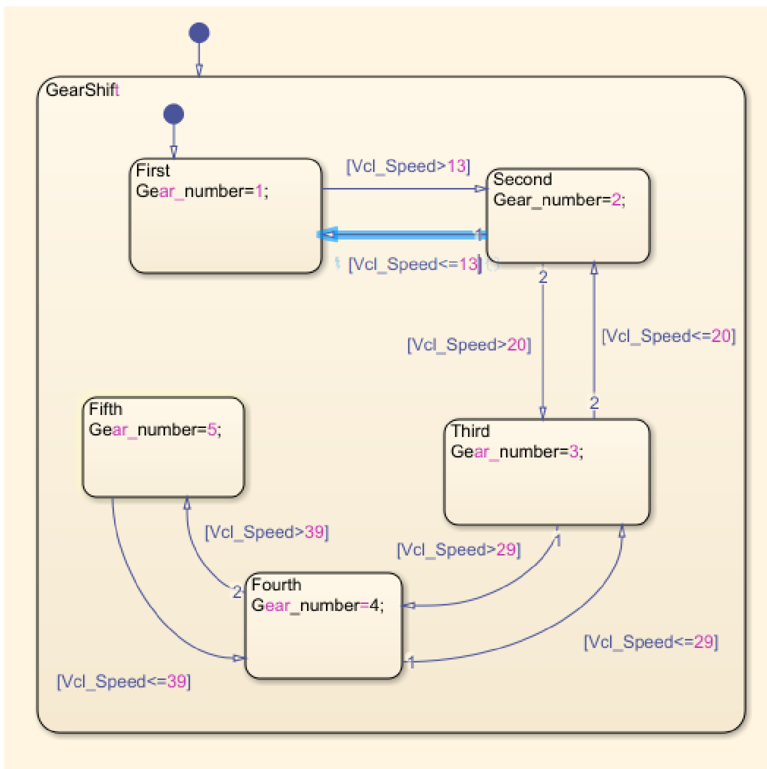


Fig. 6- Mode Logic for Gear Shifting for optimum fuel consumption

- <u>*Designing of Electronic components*</u>: In motor throttle is maintained with the help of pulse width modulation which works on the basis of Continuously switch the power on and off according to the duty cycle given. The duty cycle given here is used as a throttle control. The frequency of the PWM determines how many times switch will turn on and off. In the case discussed frequency is taken 0.1 kHz. The connections of PWM block is shown in Fig.7. Battery pack was modeled according to base voltage of the motor i.e. 96V. Battery contains 24 cells of four volts connected in series which is shown in fig. 8. The cell includes a very basic design with a load resistor in series with RC. The load resistor is temperature dependent and it decides how much power can be extracted out from the battery. This is the reason why in electric vehicles battery cooling is very important. The load resistor is used for instantaneous response and the RC is used for the delayed response in a pulse.

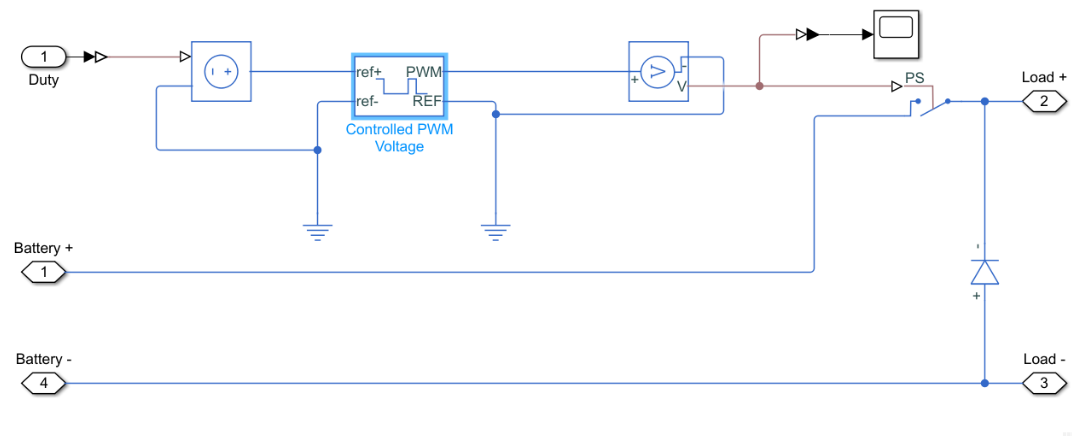


Fig.7- PWM

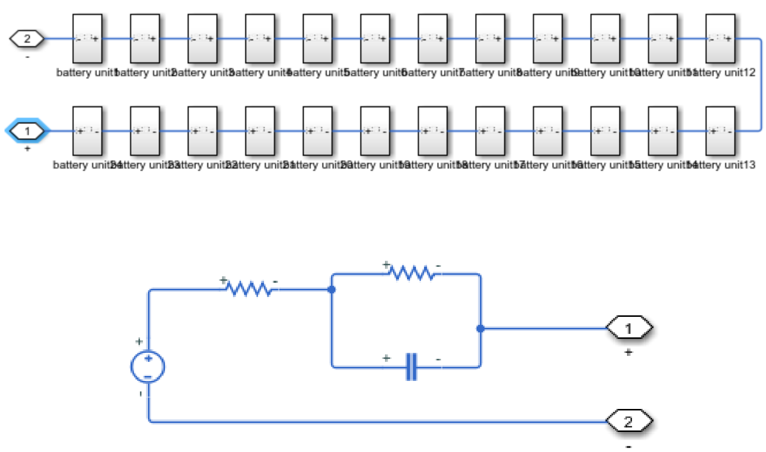


Fig.8- Battery pack (above) and Cell (below)

- *Mode logic for Hybrid Electric vehicle*: The most important part when designing any hybrid vehicle is the on/off strategy of different components. The modal control algorithms use the driver demand and system feedback inputs to satisfy the demand while optimizing the driveline system efficiency and minimizing the emissions [10]. Up to three fundamental operating modes are possible in the hybrid vehicle which are electric only, parallel and engine only. In the model discussed Mode logic is considering two different drive cycles which are urban drive cycle and cruising. The motor in our case is used only for reducing the, “low load running” of ICE and for helping it in acceleration as in this two modes efficiency of ICE is poor as can be seen in fig.9. It is clear that while increasing the RPM in an urban drive cycle first the fuel consumption increases than reduces and reaches a steady state. Considering all these factors only motor is used for propulsion of the vehicle below 30km/hr. Other than this motor assists ICE in accelerating whenever the demand of acceleration is greater than 2m/sec^2 and when vehicle speed exceeds 120 km/hr as again at higher RPMs fuel efficiency drop down seriously which can be seen in Fig. 5. The mode logic also covers brake control in which according to speed of vehicle and braking requirements brakes are applied. The mode logic is shown in the figure 10.

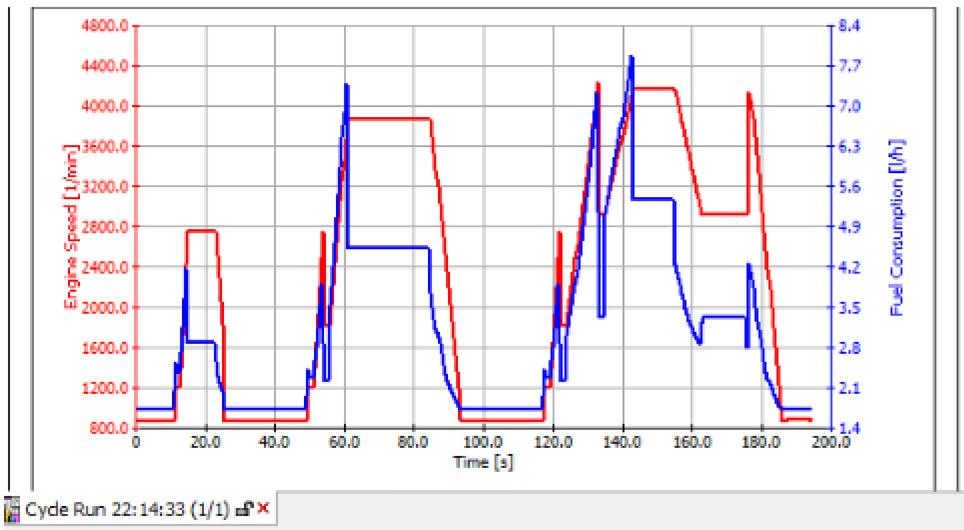


Fig. 9- Increase in fuel consumption with the RPM

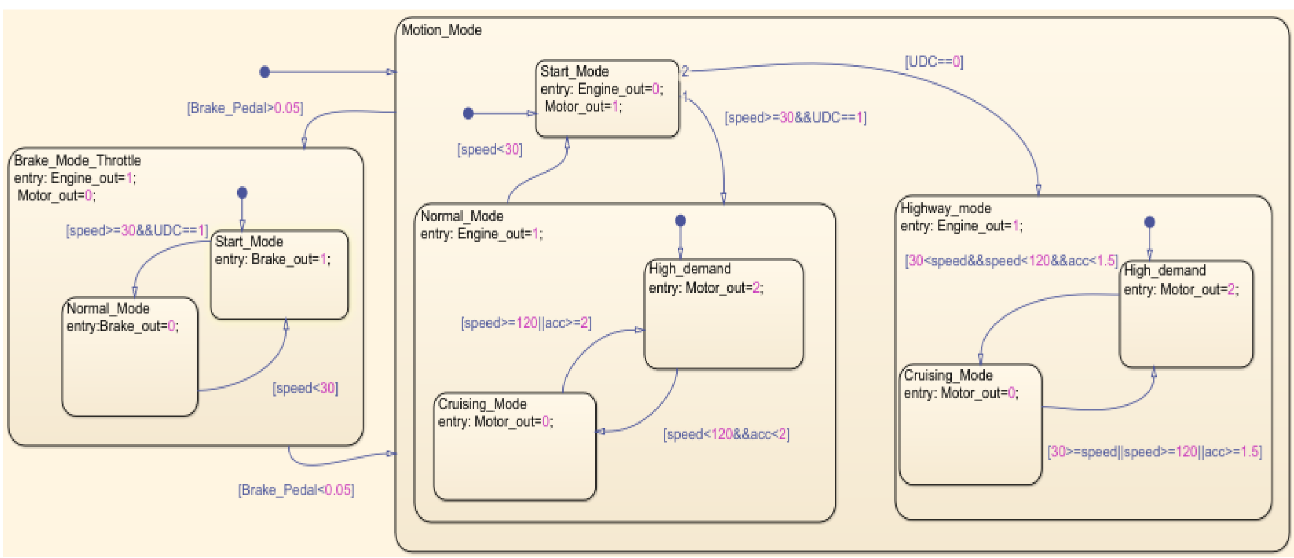


Fig.10-Mode Logic for different states of HEV

Models of Different Components in MATLAB/Simscape

Modeling of each and every component was performed on Simscape which is part of simulink. It is a platform on which physical modeling is possible. Physical modeling means that all the models will look same as the physical components for example when designing a battery cell, resistors and capacitors are connected in parallel and series same as in any physical system this can be seen in Fig.8. The equation based approach which is used in simulink is a complex approach for a Hybrid electric vehicle and so simscape is used here in which equations work on the back of each block and just parameterization is needed on the user side.

Modeling consists of systems and sub-systems for each component. The entire major models which include engine subsystem, motor subsystem, Control system for hybrid and complete power train are discussed below and shown in fig 11.

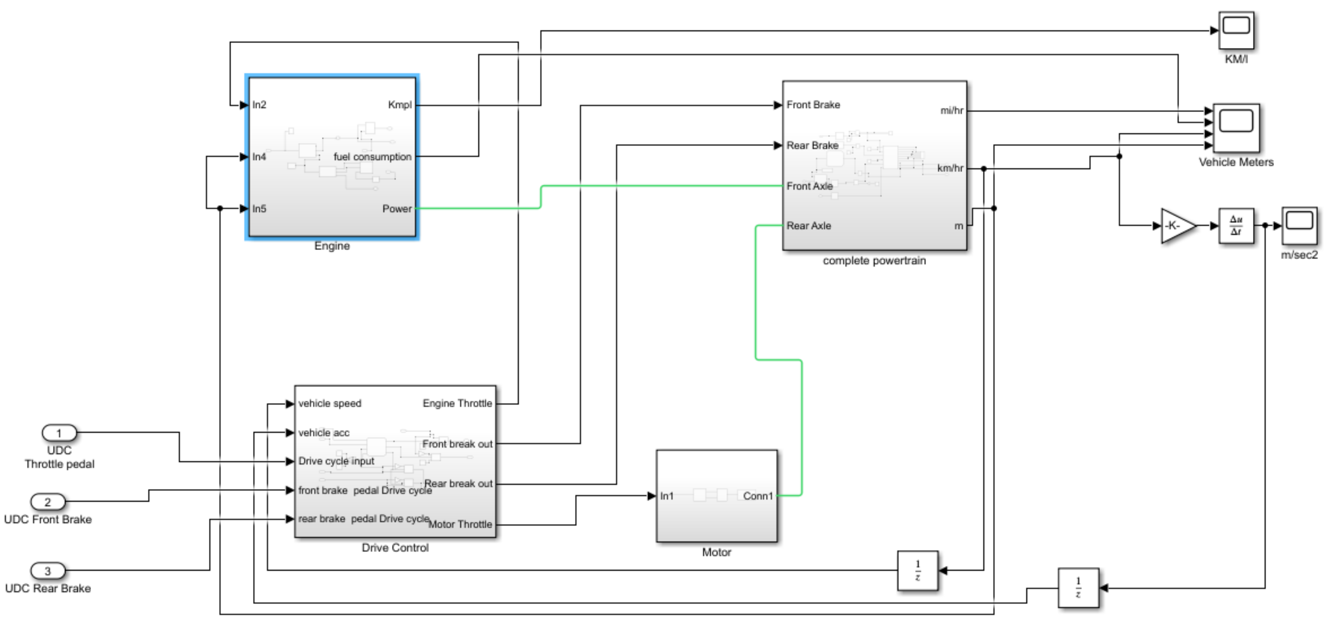


Fig. 11-Complete HEV Model for Urban Drive Cycle

- *Engine Subsystem*: It consists of Generic Engine block which describes the 4 cylinder SI engine of the model, It is connected via a physical connection to engine sensor block where different sensors are modeled for analyzing of torque, RPM, power and brake mean effective pressure of the system. Another output of generic engine block goes to the fuel check block which converts the unit of fuel consumption coming from the engine from g/sec to km/l which is also called mileage. This sub system also includes the emission measurement block which takes the RPM and torque values from the sensor system and with the help of a lookup table it gives output in grams per km of different emissions which are NOX, CO, HC and CO_2. Complete engine subsystem can be seen in Fig. 12.

- *Motor subsystem:* It consists of the DC motor block which acts as a BLDC motor it is connected via electrical connections to the battery subsystem which is discussed in last section. It is also connected to the sensor subsystem which calculates motor power, RPM and torque. The whole system gets input from the mode logic and sends physical output to power train as shown in Fig. 13

- *Mode Logic Subsystem:* This system consists of different switching modes according to driving requirements and the core of this subsystem is mode logic state flow which is explained in detail in the last section. In the state flow chart the switching of modes can be seen visually as it highlights the current mode in which the system is running in. Mode logic subsystem is shown in Fig14.

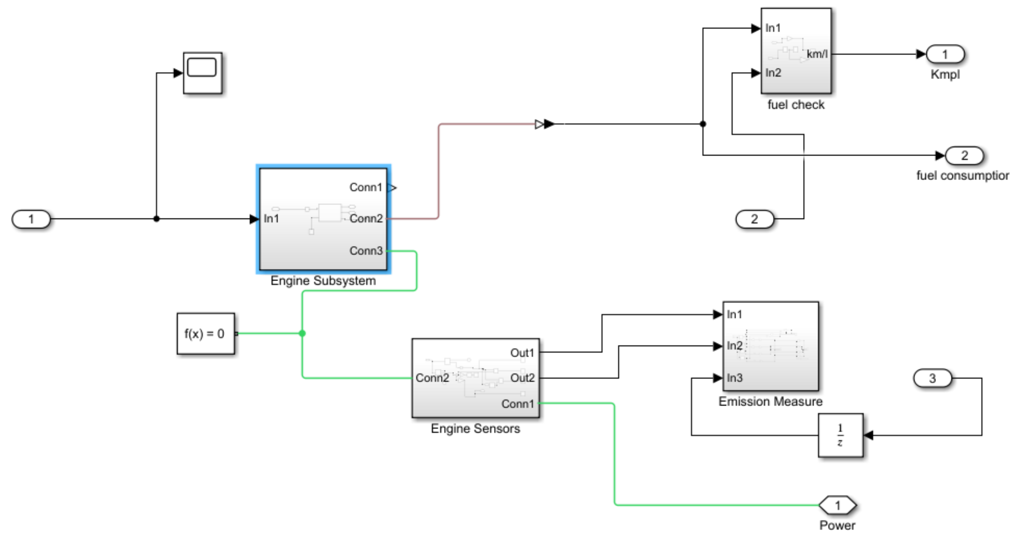


Fig. 12- Engine Subsystem

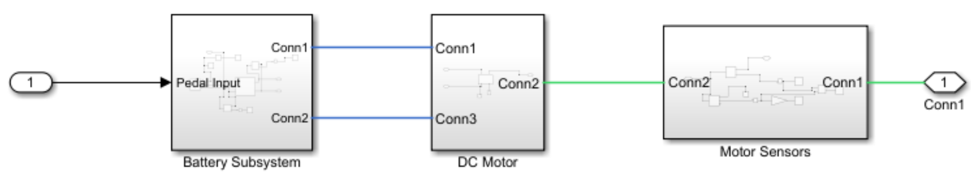


Fig. 13- Motor Subsystem

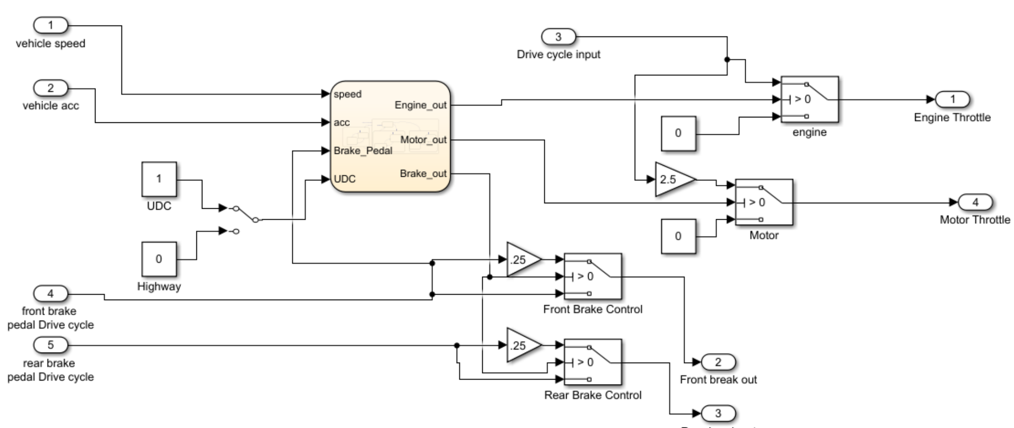


Fig. 14- Mode Control Subsystem

- <u>*Drive train subsystem*</u>: It consist of many of other system which includes vehicle subsystem, gear subsystem, gear state flow and final drive gear blocks for motor and engine. The power coming from the engine passes through gear box, final drive and torque sensor and reaches to wheels. Similarly the power from the motor passes through the final drive and goes into the rear wheels. The brake input from the brake pedal is converted to break force through a lookup table. Inside the vehicle body subsystem there are brake subsystem, vehicle dynamics subsystem and sensors for calculating speed of the vehicle and distance covered by the vehicle. The brakes and final drive physical signals are connected to front and rear axle of the vehicle dynamics block which is also connected to wheels block. In the case discussed half car model is used for system analysis and vehicle is considered symmetrical about x axis. The drive train subsystem can be seen in the fig.15 and the vehicle dynamics block can be seen in fig. 16.

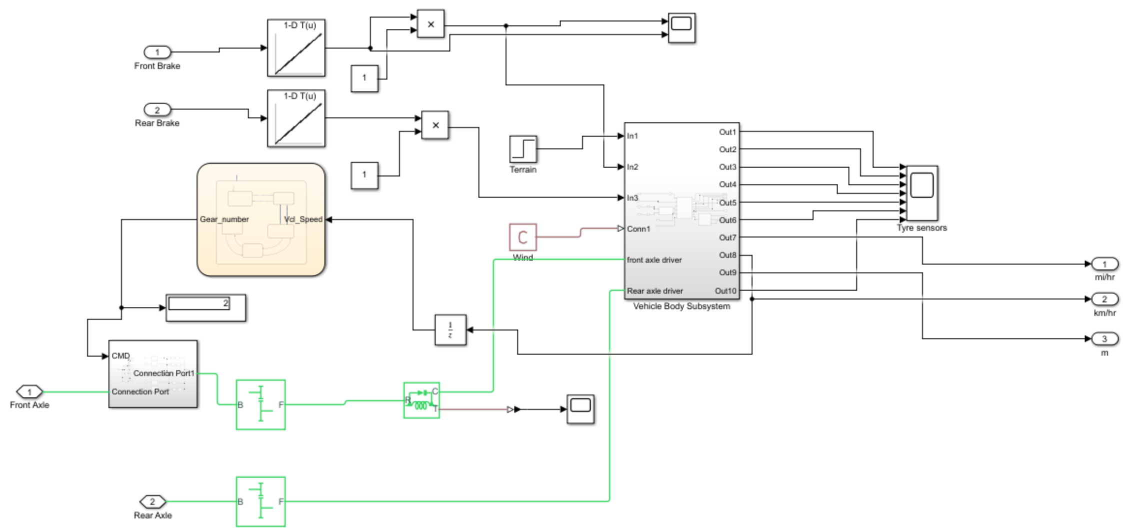


Fig.15- Drive train subsystem

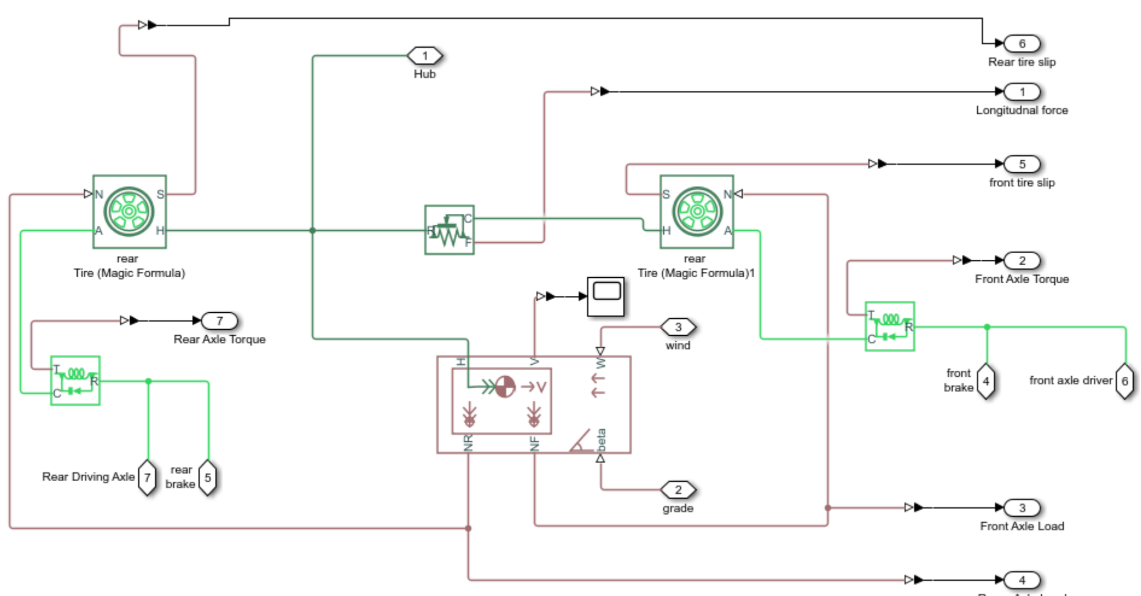


Fig.16- Vehicle dynamics subsystem

Result and Discussion

Three different road conditions viz. urban drive cycle (UDC), Highway cruising and wide open throttle were tested in the model and three parameters were analyzed including Fuel consumption, Emissions and Performance parameters which are discussed below:

1. *Urban Drive Cycle*: It is drive cycle which involves frequent start-stop and constant speed is not achieved in this drive-cycle as shown in fig. 17. Because of very much instability in the requirement the engine can't provide a better efficiency. Another important point is that in UDC the vehicle mostly runs at slow speed which again reduces the load on engine and at lower loads it gives poor efficiency for this purpose the model proposed proved to be a better alternative. Fig. 18 shows the throttle and brake pedal positions for this drive-cycle.

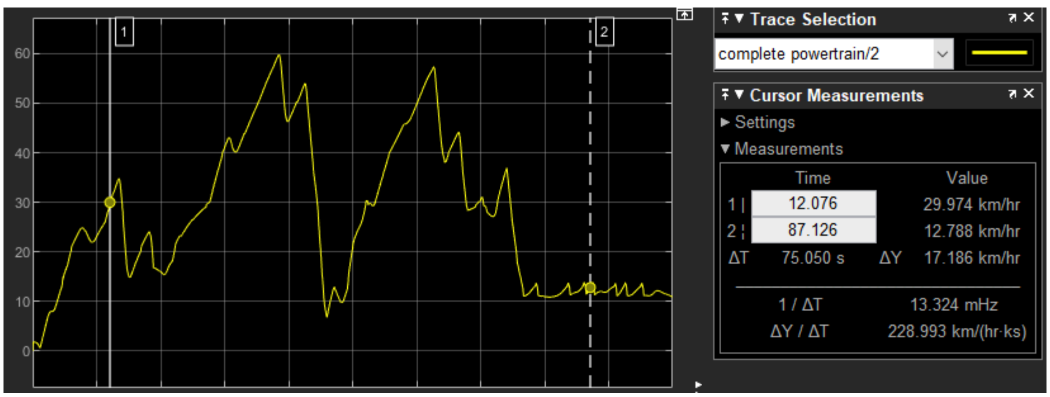


Fig.17- Urban Drive Cycle in HEV

Throttle Pedal Brake Pedal

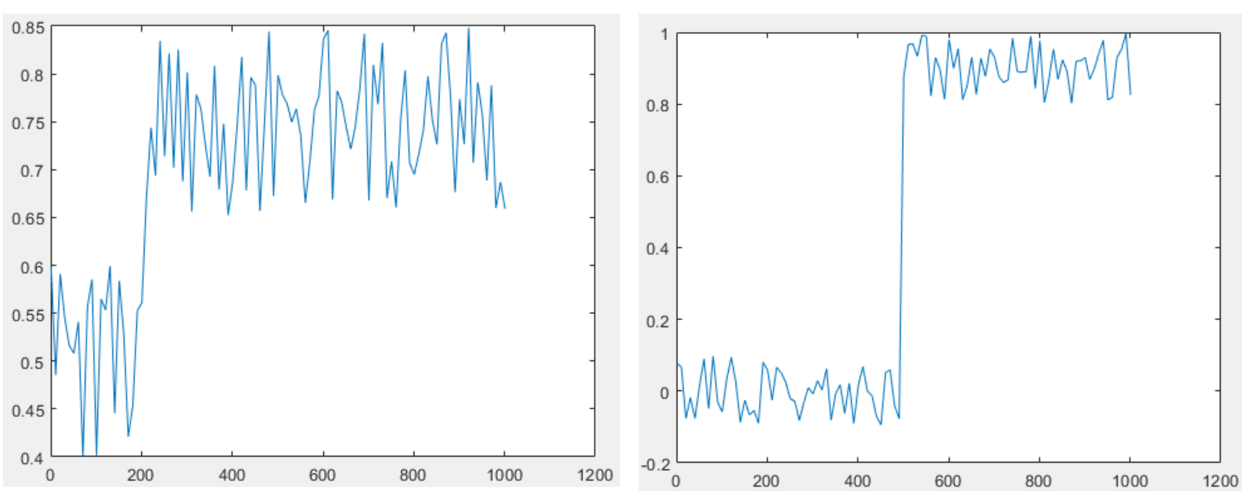


Fig.18- Urban Drive Cycle Pedal Inputs

The fuel consumption of ICE comes best at optimum load and optimum RPM for this vehicle RPM of engine comes around 2100 RPM this can be seen in fig. 5 which shows fuel consumption with RPM here the main objective is to run engine around this RPM fig. 19 shows two graphs comparing RPM of conventional vehicle to HEV. It can be analyzed from the figure that there is a lot of instability in RPM in conventional vehicle which causes high fuel consumption this can also be verified from the simulation run on AVL cruise shown in fig 9. Apart from this the peaks in the graph are more high in conventional vehicle and in HEV the RPM peaks remain close to 2100 RPM this indicates that there must be improve in fuel efficiency in HEV.

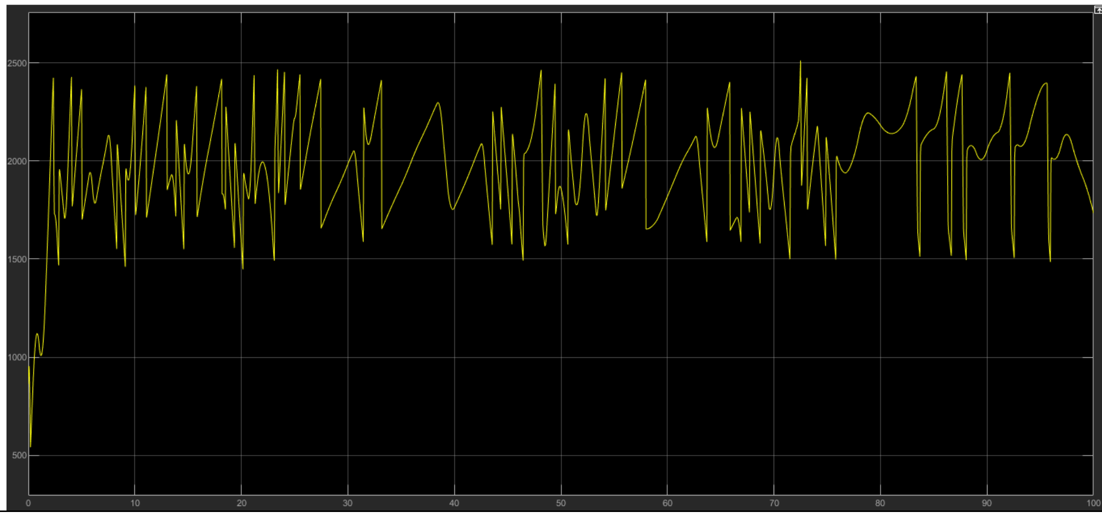
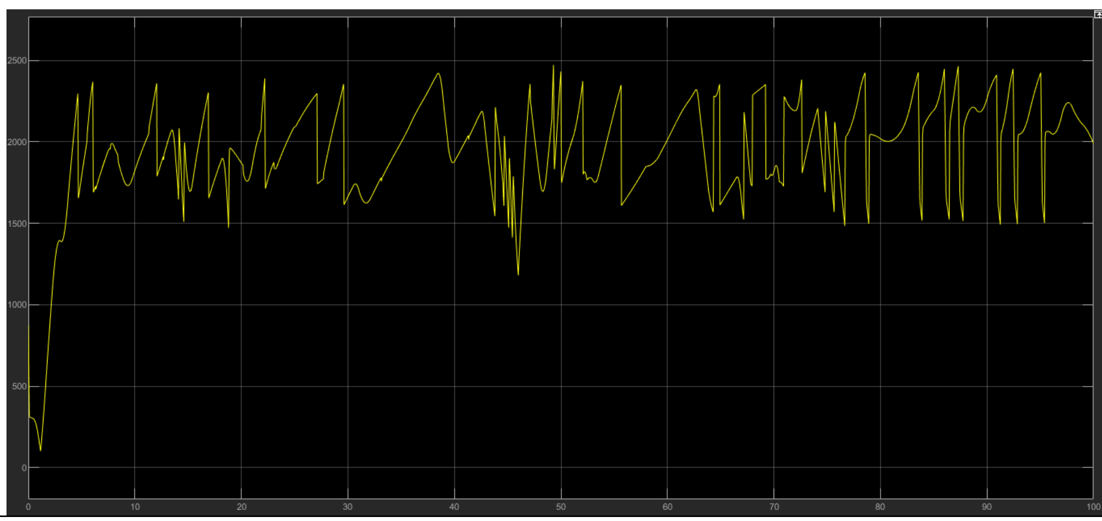
Conven -tional Vehicle (Ford ikon)	
HEV	

Fig. 19- RPM of engine in conventional vehicle and HEV

Comparison between the fuel consumption of two cases is the next process but for that it is necessary that engine mapping must be done for conventional vehicle. For this the max achievable mileage for urban drive cycle is taken as approved by the Ford. For this model it is 10kmpl as mentioned in Table 2.acoding to this peak value different datasets were created and the one in which the maximum mileage was coming 10km/l was used. After getting this data it was put in HEV model and the simulation shows a significant improvement in fuel economy as can be seen in Fig. 20. The max mileage after converting is 12.31km/l this implies that there is an improvement of 23% in fuel economy in urban drive cycle.

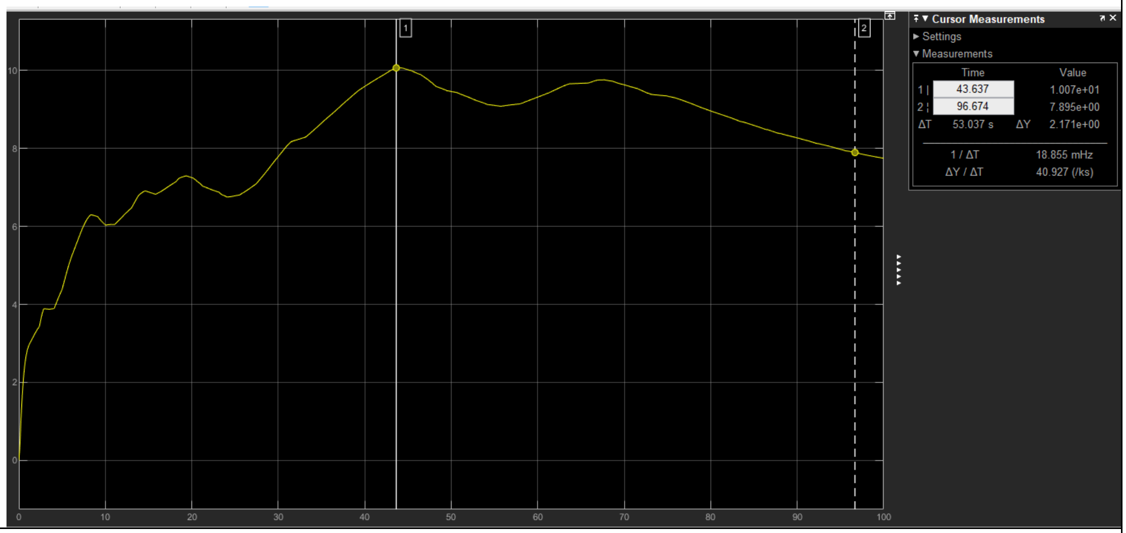
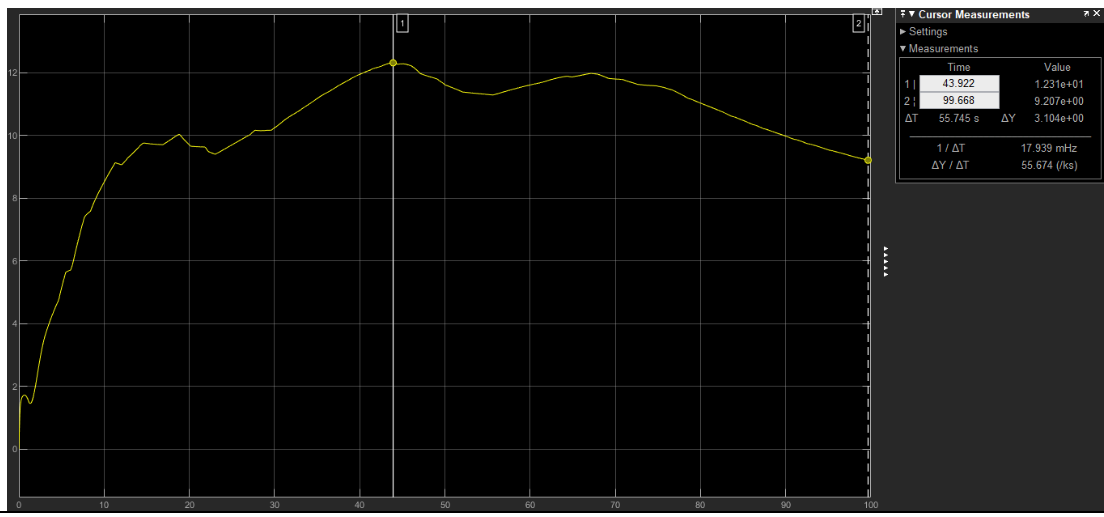
Conven-tional Vehicle (Ford ikon)	
HEV	

Fig. 20- Fuel consumption graphs for conventional and HEV case

After analyzing the fuel consumption another comparison to be done is for emissions as it is known that BS6 norms are striking which have very stringent rules, using a HEV conversion can be beneficial. Four main emissions including NO_X, HC, CO and CO_2 were compared for both the vehicles. Fig. 21 shows the emission norms in India. The conventional vehicle is a 2010 model and at that time BS 4 was introduced and so its emissions are based on BS3 standards. In this case also for mapping the data first assumption is considered for conventional vehicle according to trend shown in Fig.22 and then the values are put in such a way that, they just compliant with BS4 norms. After getting satisfying results for conventional vehicle same data is used in HEV to check the percentage change. Emission subsystem can also be seen in Fig. 23 in which data driven approach is used to calculate emissions. In fig 24 different emissions are compared for conventional vehicle and HEV.

Year	Reference	CO	HC	HC+NO_x	NO_x
1991	–	14.3–27.1	2.0–2.9	–	
1996	–	8.68–12.4	–	3.00–4.36	
1998*	–	4.34–6.20	–	1.50–2.18	
2000	Euro 1	2.72–6.90	–	0.97–1.70	
2005†	Euro 2	2.2–5.0	–	0.5–0.7	
2010†	Euro 3	2.3 4.17 5.22	0.20 0.25 0.29	–	0.15 0.18 0.21
2010‡	Euro 4	1.0 1.81 2.27	0.1 0.13 0.16	–	0.08 0.10 0.11

* For catalytic converter fitted vehicles.

† Earlier introduction in selected regions, see Table 1. ‡ only in selected regions, see Table 1.

Fig. 21- comparison between BS3 and BS4 norms.

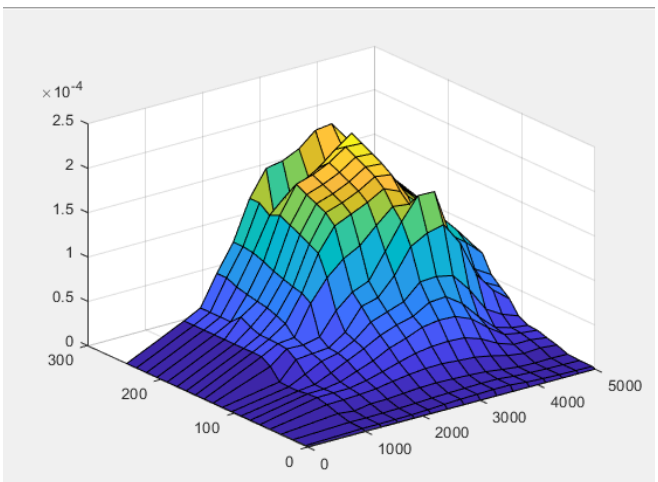


Fig. 22- NOx emission trends in SI engine

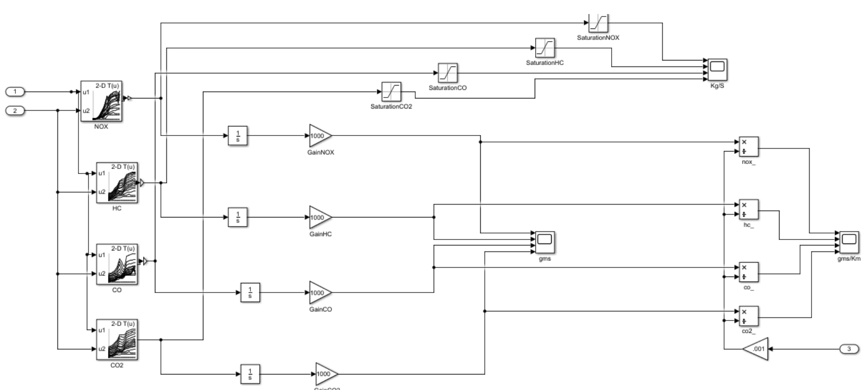
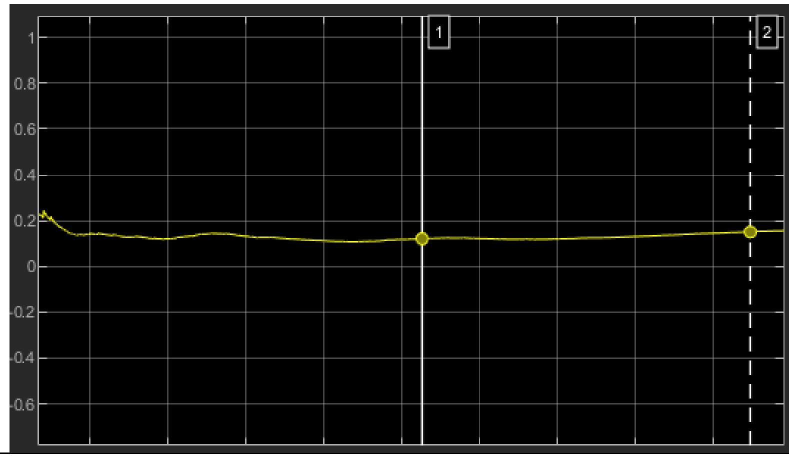
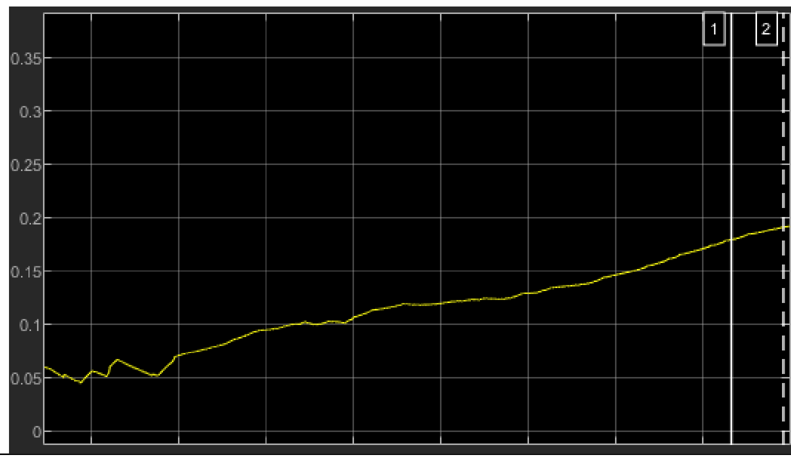
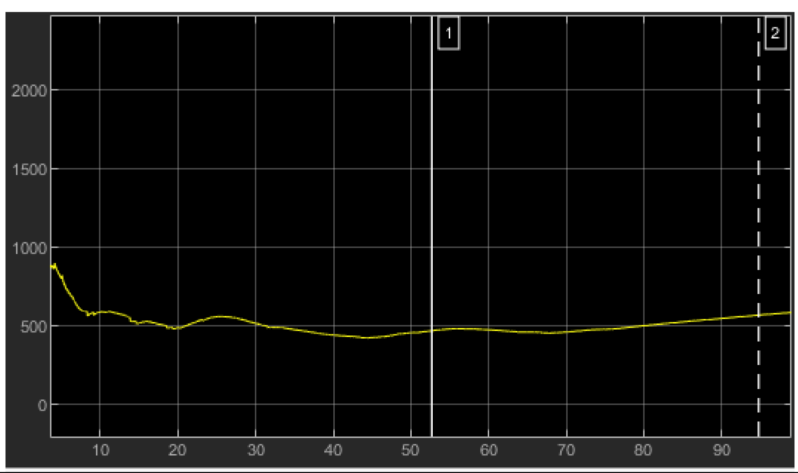
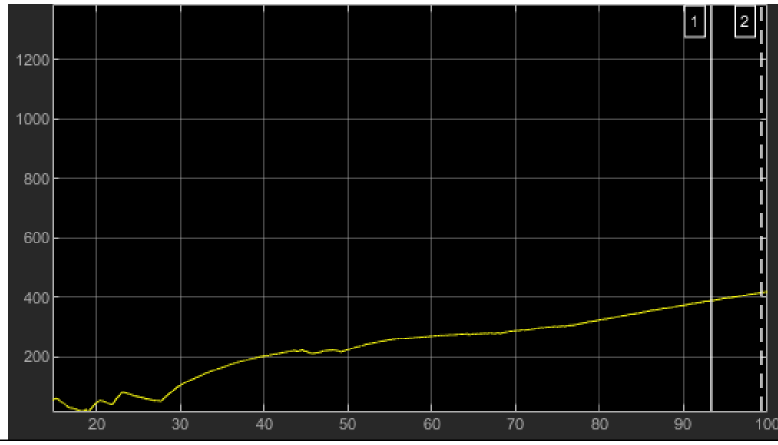
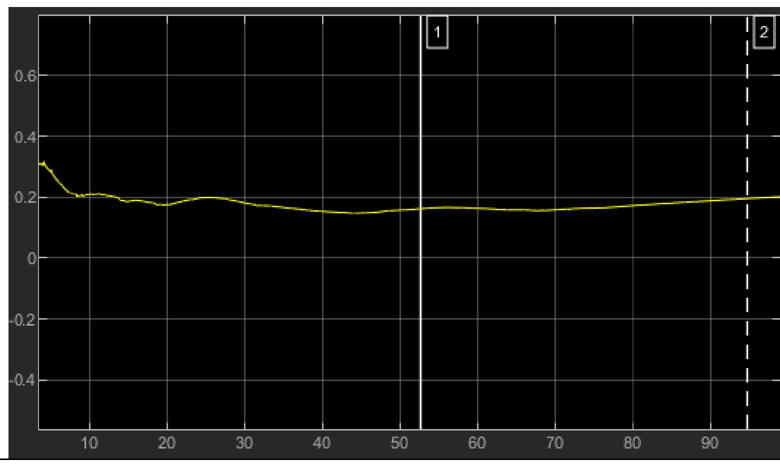
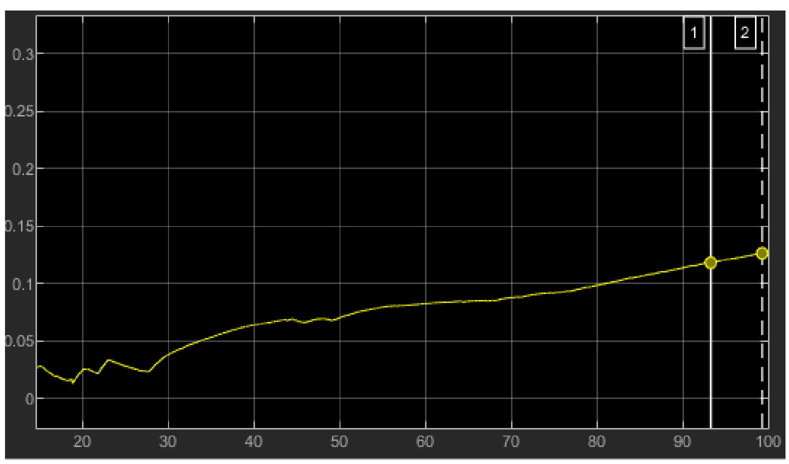
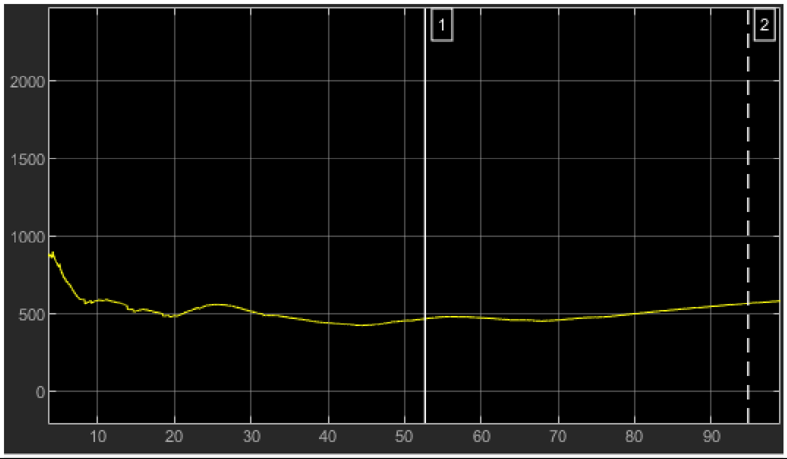
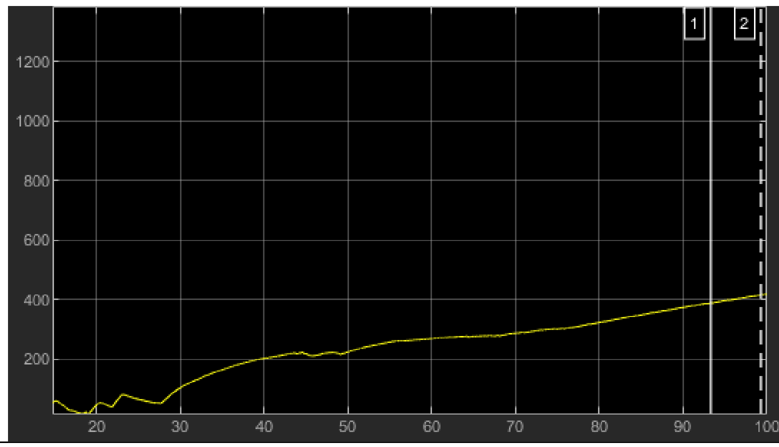


Fig. 23- Emission Subsystem

Emission Gas	NO_x
Conventional	
HEV	
Emission Gas	CO
Conventional	

<table>
<tr><td>HEV</td><td>
</td></tr>
<tr><td>Emission Gas</td><td>HC</td></tr>
<tr><td>Conventional</td><td>
</td></tr>
<tr><td>HEV</td><td>
</td></tr>
</table>

Emission Gas	CO2
Conventional	
HEV	

From the above figures it is clear that as we assist our conventional vehicle with motor HC, CO andCO_2 reduces significantly and they are approaching toward BS4 norms standard. This may be attributed to the fact that as the engine runs at optimum RPMs the overall emissions reduce because of complete combustion of fuel due to availability of proper a/f ratio. Whereas the NO_X emissions increased as at optimum a/f ratio the conversion rate of chemical energy to heat energy increases because of which high temp rises in the combustion chamber which increase dissociation of N_2 to form NO_X[10].

2. Cruising drive cycle: This type of drive cycle is encountered on highway the throttle input is kept more or less constant and there is gradual change in speed every time. The Drive cycle input given in this case is shown in fig 24. In this case the use of motor is heavily reduced and there is no need for motor to assist the engine as this did not make any significant impact on fuel consumption. However the emission are changed but NO_X increases in this case also which makes adding motor more unprofitable. The drive cycle curve is shown in fig 25. The mileage of both the modes with and without is shown in table 6.

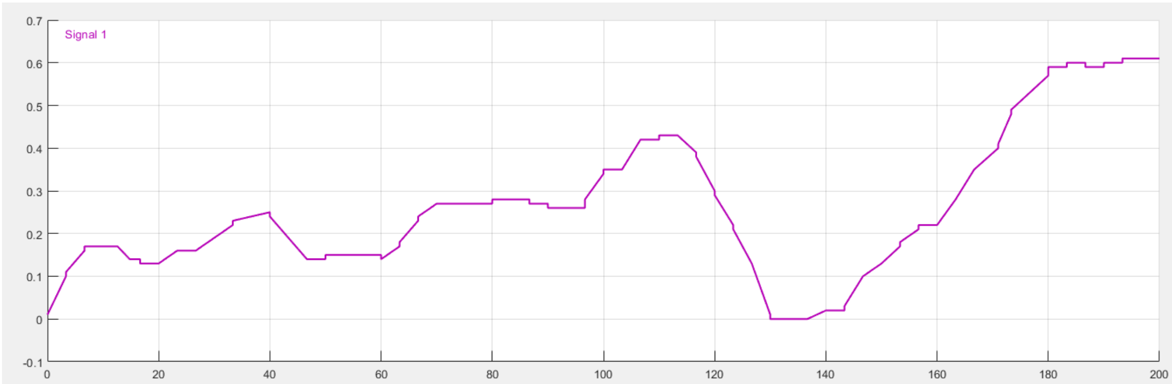


Fig. 24- Highway throttle pedal input

Conventional Vehicle

HEV

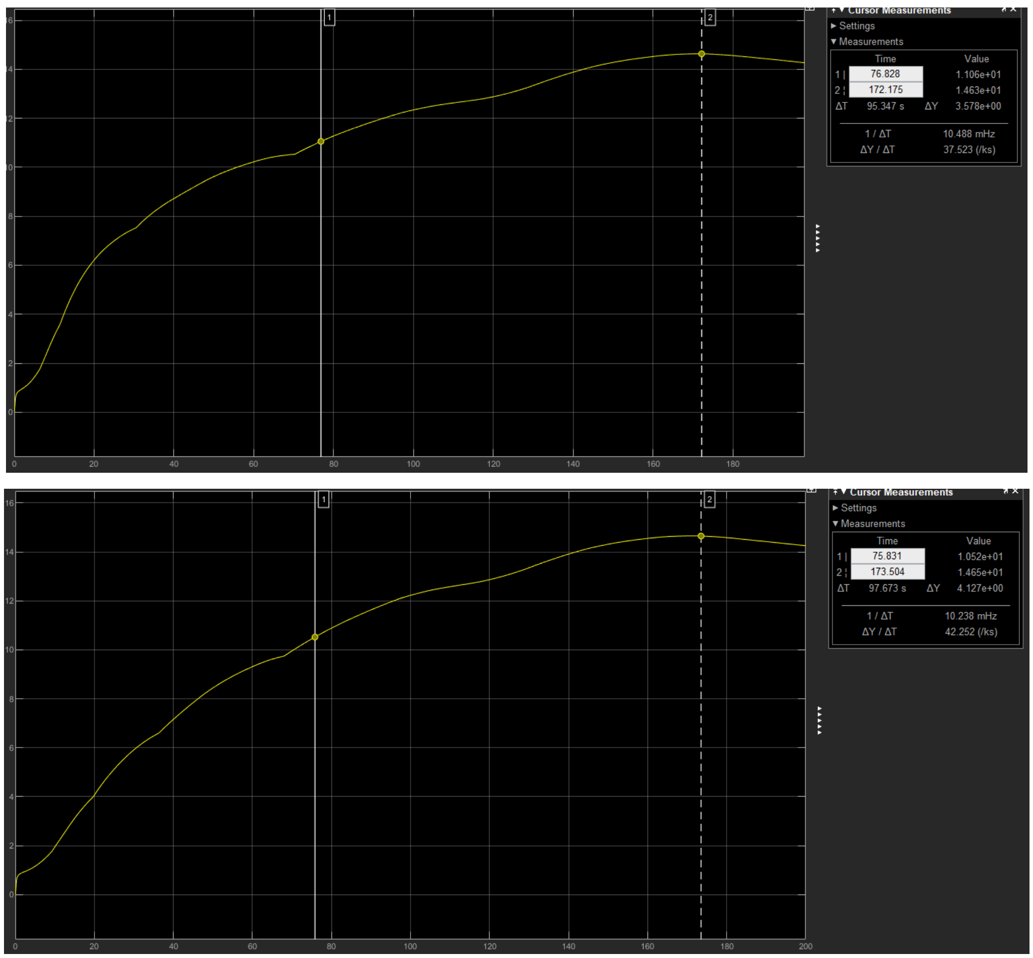


Fig. 26- Fuel economy comparison between conventional vehicle and HEV

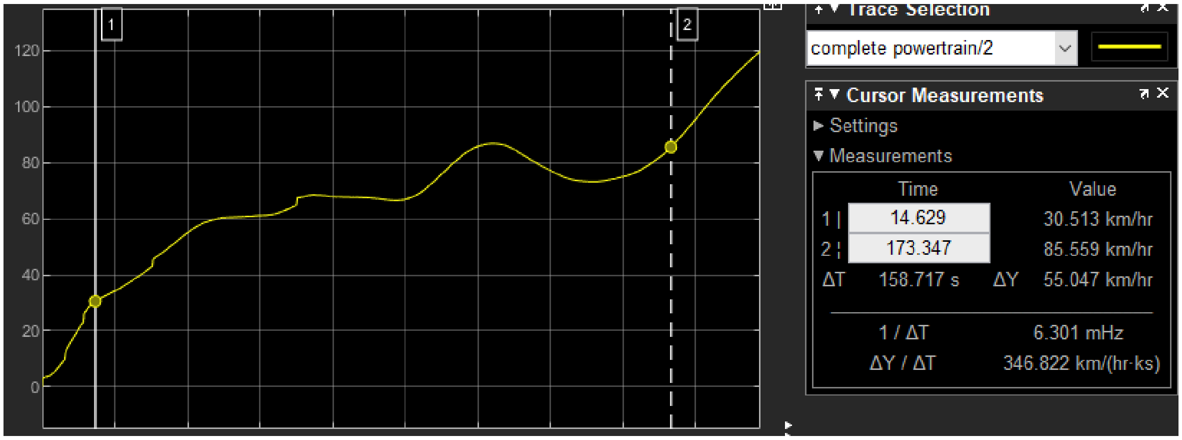


Fig. 25- Highway velocity output HEV

3. Wide open throttle: This condition of maximum acceleration to test the performance of the vehicle. In this mode again motor has no importance and hence it is not used. The max velocity which can be achievable by the vehicle is coming near to what Ford claims and the 0-100 km/hr acceleration is achieved at near 15 sec which Ford also claims. The max velocity attainment from zero speed is shown in Fig.27 and Fig. 28.

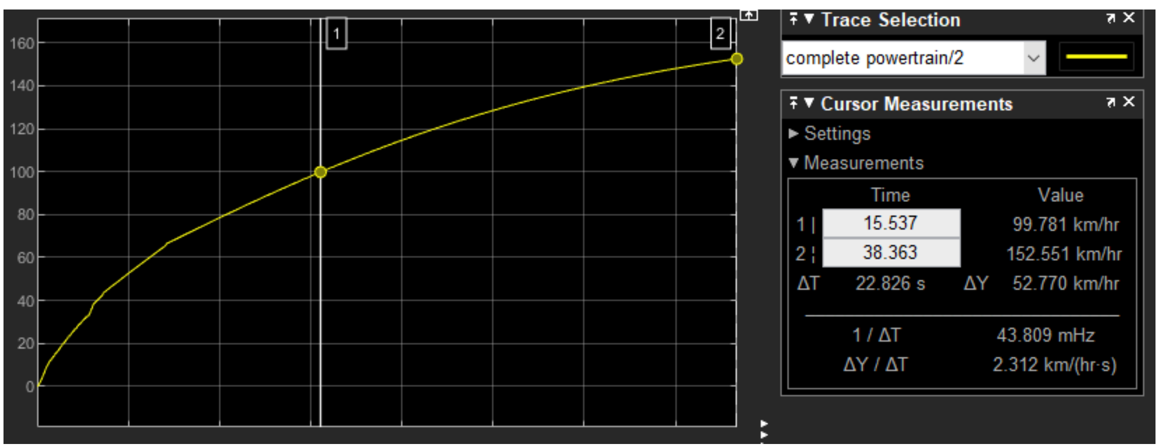


Fig. 27- Wide open Throttle velocity curve

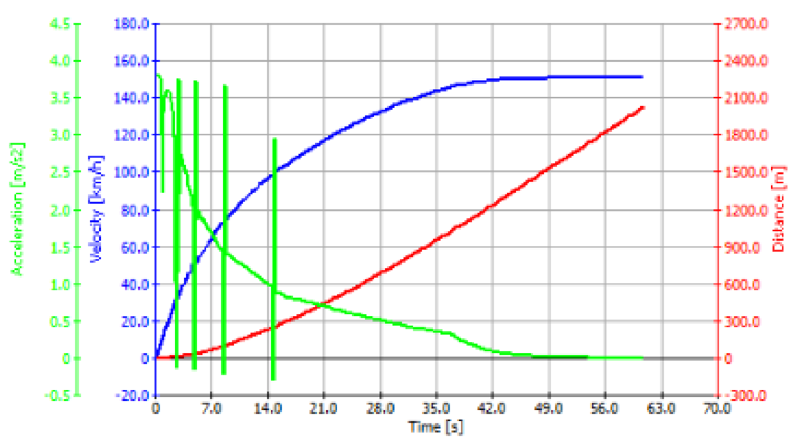


Fig. 27-Max acceleration condition tested on AVL cruise.

Chapter *4*

Conclusions

The report discussed about the emerging need of HEVs, HEVs classification, there pros and cons in different operating conditions and their design procedure, it was found that Parallel hybrid is most suitable configuration for urban needs with mild or power hybrids, work of many researches was analyzed and according to that the scope in conversion of conventional vehicle to HEV was found. According to the simulation following conclusions were made.

- The Design of power-train is a complex process and step by step process needs to be done "AVL cruise" is one of the best software for analysis if longitudinal dynamics of the vehicle and it can be used for designing of proper gear ratios and shifting logic.
- Designing of Mode control logic is most important aspect of designing a HEV as it acts as brain of vehicle and it decides the fuel consumption and emissions of the vehicle
- Converted HEV proves to be a great option for reducing the fuel consumption. Frequent star and stop in UDC makes it a perfect condition for the model discussed.
- In cruising mode there is no need for HEV mode operation as there is trivial effect on fuel economy.
- In all the cases adding the motor is reducing the exaust emissions like CO, HC and CO_2 but in HEV mode NO_x production is increased.
- The increased NO_x can be controlled by adding EGR to the system.

Future work

- The optimization of Mode logic can be done any level and for that purpose machine learning algorithms will be used to optimize the system.
- Regenerative Braking will be added to the model which will again improve the efficiency of the system.
- The model created on MATLAB will be used for analyzing all the scenarios discussed, for vehicle, "swift-dzire" as its real time data can be calculated in our workshop.

References

[1] Ehsani, Mehrdad, Khwaja M. Rahman, and Hamid A. Toliyat. "Propulsion system design of electric and hybrid vehicles." *IEEE Transactions on industrial electronics* 44.1 (1997): 19-27.

[2] https://en.wikipedia.org/wiki/Hybrid_electric_vehicle#History

[3] Emadi, Ali, Young Joo Lee, and Kaushik Rajashekara. "Power electronics and motor drives in electric, hybrid electric, and plug-in hybrid electric vehicles." *IEEE Transactions on industrial electronics* 55.6 (2008): 2237-2245.

[4] Mahapatra, Saurabh, et al. *Model-based design for hybrid electric vehicle systems*. No. 2008-01-0085. SAE Technical Paper, 2008.

[5] Koprubasi, Kerem, et al. *Application of Model-Based Design Techniques for the Control Development and Optimization of a Hybrid-Electric Vehicle*. No. 2009-01-0143. SAE Technical Paper, 2009.

[6] Rahman, Imran, et al. "Review of recent trends in optimization techniques for plug-in hybrid, and electric vehicle charging infrastructures." *Renewable and Sustainable Energy Reviews* 58 (2016): 1039-1047.

[7] Model-Based Design for Hybrid Electric Vehicle Systems. 2008-01-0085 Copyright © 2008 The MathWorks, Inc.

[8] Butler, Karen L., Mehrdad Ehsani, and Preyas Kamath. "A Matlab-based modeling and simulation package for electric and hybrid electric vehicle design." *IEEE Transactions on vehicular technology* 48.6 (1999): 1770-1778.

[9] McCann, Roy, Anh T. Le, and David Traore. "Model predictive control for time-delay compensation of a switched reluctance motor drive in smart building applications." *2008 IEEE Industry Applications Society Annual Meeting*. IEEE, 2008.

[10] Husain, Iqbal. *Electric and hybrid vehicles: design fundamentals*. CRC press, 2010.