A review on Hybrid Electric Vehicle and simulation on Hybrid Electric Vehicle Drivetrain

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Abstract. This paper discusses about the Hybrid Electric Vehicle (HEV) and the simulation on the Parallel Hybrid Electric Vehicle Drivetrain. The concept and the classification of the HEV is discussed here and the simulation and analysis of a drivetrain for Parallel Electric Hybrid Engine (PHEV) was formulated on MATLAB Simulink. The methodology of simulation was to accelerate or decelerate the vehicle independently with the electric motor with engine running at constant speed. And the parameters such as electric motor and engine power were compared and observed. And research on CO₂ emission and fuel consumption was made between the PHEV and Conventional Vehicle (ICE Vehicle). And the conclusion was made according to the research and the simulation that the development of HEV will have a great potential in fuel economy improvement.

1. Introduction
This paper discusses about the Hybrid electric vehicle and the simulation on the Parallel Hybrid Electric Vehicle Drivetrain. The first Hybrid Electric Vehicle (HEV) was invented in 1889 by William H. Patton and was used in trams and small locomotives and later it was used smaller vehicles such as cars, SUVs, etc but it were not successful because of no oil shortage at that time but the demand grew up in late 1900s during the rise in oil crisis and then many companies shifted their agenda from performance vehicle to efficiency and fuel economical vehicles such as Toyota Prius which was introduced at that time was having great impact on the market and nearly in 2008, the were many HEVs in the markets and with better efficiency. The EHV s were a booming concept, so every company launched this kind of vehicle like Range Rover Hybrid, Honda Vezel-Hybrid SUV, Audi Q5-Hybrid, BMW 5-Series-Active-Hybrid, BMW 3-series-Hybrid, Ford C-Max-Hybrid, Acura ILX-Hybrid, etc.
A Hybrid Electric Vehicle (HEV) is a type of hybrid vehicle which consists of combination of two power source to drive the vehicle. The two power sources are ICE (Internal Combustion Engine) and Electric Propulsion System (electric source of energy). HEVs basically works efficiently by switching the power source of the vehicle from ICE to Electric propulsion or vice versa as per the driving conditions or can be driven using both the power source on high performance conditions of the vehicle. Basically, the aim of these concept was to build a fuel efficient and less emission car power source. The concept has been a successful and it has been used in many vehicles including trucks, buses and pickup trucks.
The Drivetrain is known to be a group of components which transfers the power generated from the engine to the driving wheels excluding the engine or power source and the wheels. And a simple drivetrain transfers the power generated from the engine to the transmission which is engaged with the flywheel by clutch and the power from the transmission is transferred to the rear differential by long propeller or drive shaft from where power is transferred to axle and from axle to the two wheels which drives the vehicle. There is also a term called “Powertrain”, the difference between the power train and
drivetrain is just that the powertrain includes all the drivetrain components and includes the power source components such as engine and wheels. The Drivetrain changes depending on the type of the vehicle such as Front-wheel, Rear-wheel or Four-wheel drive etc. or on the type of the power source such as for electric vehicles, hybrid electric vehicle, Hydraulic hybrid vehicles etc. The hybrid electric vehicle Powertrain has more no of components and more complexity than a simple ICE Powertrain due more electrification. In HEV powertrain, electrical energy is also used as along with engine to produce torque, so the drive train are designed in such a way that the torque of both sources is combined and distributed to the wheels. And the drivetrain uses the power control units to control or stop the power from the engine or electric motor.

Basically, the HEV drivetrain consists of ICE, Electric motor, Battery, energy convertor, Transmission and Power Control Unit (PCU). The HEV drives their wheels on two power source ICE and Electric Motor which are connected to Transmission which are connected to the axle and then to the wheels. The Electric Motor is powered by battery, it is connected to the DC-DC convertor to converts the voltage of the current flowing through it and supply it to the motor. The power sources are controlled by power management unit which commands the sources to switch On/Off according to the performance required and optimization of the vehicle.

The HEV has Power Management unit or Power Control Unit which is built with control strategy [1], [2] for power optimization and it controls and commands the power source components based on the driving condition. the control unit continuously observe the vehicle performance parameters and efficiency parameters and to optimize these parameters it commands the power sources of the vehicle. And the control strategy are designed on different conditions such as 1) when the vehicle is travelling with low speed or less acceleration and the performance required is less and the battery is fully charged, so the vehicle operates on Electric motor powered by battery and engine will be shutoff, 2) when the vehicle is accelerating or requires high performance with engine on and the battery charge is full that time, electric motor is started to assist the engine for acceleration and to reduce fuel emissions because at high performance more fuel is consumed, 3) when the vehicle is cruising with engine power and battery charge is low, the engine power is transferred to wheel as well as to the electric motor which becomes generator and generate electricity which is stored in the battery for later requirements, 4) The battery is also charged by other components of the vehicle such as regenerative braking system (RBS) and regenerative shock absorbers (RSA), the RBS supplies electricity to battery during the braking of the vehicle, the energy wasted in braking is used by the generator to generate and store electricity in the battery and similarly the RSA, due uneven roads the vehicle gets impulsive shocks and this shocks are used to generate electricity. These regenerative energy sources decrease the fuel consumption which decreases the emissions and increases the range of the vehicle and increases the economy and efficiency of the vehicle.

2. Classification of HEV
There are three main types of HEV drivetrains which are Parallel mode, Series mode and Power-split: -
Parallel: -The basic HEV powertrain consists of Electric motor, ICE, Generator, battery, power convertor and transmission. In the Parallel HEV the electric motor system and the ICE are arranged parallely and both combines their power and drives the wheels. And this configuration is more efficient than the series HEV. It can also give instantaneous power during high performance requirements by electric motor assisting the ICE to build more power. But it requires a complex linkage between the engine and motor shaft to join and give combined power.
Series: - In the series HEV the engine doesn’t have any mechanical linkage with the wheels, and they don’t have any transmission because the wheels are driven only by the motors. The engine is connected to the generator which generates the electricity then with help of charger it is stored into the battery, then from the battery the controllers supplies the current to the Electric Motor and which drives the wheels. the Series HEV can run on motor independently when the engine is Shut Off. The efficiency of the vehicle is less than the Parallel HEV due more no of components arranged in series HEV which increases the energy losses.
Power-Split: - Basically it is combination of both the Series and Parallel HEV powertrain, the Power-split HEV power train starts from the engine which produces the power from where it is divided in to
two paths where one goes directly to the transmission and drive the wheels like conventional vehicle whereas other goes is connected to the generator which generates electricity and stores in the battery and then later use it to drive the motor which is connected after the transmission directly to the driving shaft. So here both Series and Parallel concept is used for getting the best efficiency of the vehicle according to the driving conditions.

There are also other types of HEV on basis of power source mainly electric power source such as Full HEV, Mild HEV, Plug-in HEV, Micro-hybrid etc.

**Full HEV:** - This kind of EHV can have independent power source like working just on electric propulsion system or ICE or both can work at same time to power the vehicle during high vehicle performance requirement and it electric battery doesn’t required to be charged from external charging plug but the battery gets charged by ICE itself so no external battery charging is required. They can also operate in parallel and series mode also example like “Toyota Prius”. The parallel mode uses both the electric motor and combustion engine at same time to drive the wheels whereas the series mode means the main power is the ICE and the electric motor will assist the ICE for more performance.

**Mild EHV:** - This kind of EHV also has both power sources but here the vehicle cannot work independently on the electric propulsion, here the vehicle mainly runs by both source of power at same time, but it can work at ICE independently. Example: - “Honda Accord Hybrid”. they are limited to parallel mode, so they work only on series mode.

**Plug-in EHV:** - This kind of EHV also has two power source and can run independently on electric or ICE but here the battery of electric propulsion system is not charged with the ICE but it is charged by the external charging plug that’s why it is named Plug-in EHV. Mainly the Plug-in hybrid have more capacity in battery then in Full hybrid and they range is also higher than the average Full hybrid. They can work on both series and parallel mode.

There are some other types of EHV which are not common in use like high-performance hybrids which are used in high performance cars such as “Ferrari”, “McLaren”, Etc. These Automobiles companies uses this hybrid technology to boost cars performance unlike others they do not focus fuel efficiency and they focus on performance maximization. They use the hybrid electric motors to assist the engine to maximize performance to the vehicle they use the hybrid electric technology in completely opposite way.

The HEVs are fuel efficient than conventional vehicle because of less emission generate due to electric motors. And they are cost-effective and affordable also, compared to conventional vehicle. The ICE required in HEV is lighter than the conventional one, so it makes the Vehicle lighter and more spacious. the Vehicle also decreases fuel usage which increases the driving range of the vehicle. The HEVs are also more preferred than pure Electric Vehicle (EV) [3] due to performance compromise in EV, EVs are costly and requires electric charging stations for charging which are not available outside the cities, obviously lesser emission are there but the time required for charging is 10-12 hours compared fuel engine which is too much. but in HEV, charging stations are not required for charging the battery, but it is charged by the generator, which is connected to the engine, so the power gets reused by electric motors to accelerate the vehicle. The HEVs mainly are built for economy, so there is a compromise of performance in some HEVs, the HEV also increases the maintenance of the vehicle because of complex components used and mainly due to electronic components requires skilled experts for the maintenance.

3. **Simulation methodology**

The objective here is to simulate the drivetrain for Electric Hybrid Vehicle (HEV) and study and analyze the different parameters associated with the drivetrain and its components. The simulation of powertrain is done for parallel type of HEV, in the software called MATLAB Simulink. The Parallel HEV consists of an ICE, DC-DC convertor, Battery, Electric Motor, transmission and two wheels (Because halfVehicle model is built, and only rear wheels are included).In the PHEV the ICE and Motor
output shaft are connected with mechanical coupling or any other linkage mechanism to combine and transfer the power to the transmission.

In the simulation the engine and motor are arranged parallel to each other and unlike the figure 1 above only engine is attached to the transmission and the battery is attached with the DC-DC convertor which supplies electric current to electric motor to drive the shaft and the output shaft of both the transmission and the motor are combined to combine the power produced by both the power sources. Due lack of skills in MATLAB Simulink the control strategy unit was not developed in the powertrain model to command the power source components according to the performance requirements of the vehicle. Therefore, the method used here for knowing the power requirements of the electric motor to drive the wheels was, the engine was kept On at constant throttle to deliver the power to wheels to maintain an initial speed of the vehicle. And the electric motor is used to accelerate the vehicle and maintain a constant speed and then deaccelerate back to the initial speed which means electric motor was switched On during the performance requirement and maintain the performance and then the electric motor is switched Off and the vehicle is cruising with the engine power supplied to the wheels. The Electric motor is managed with the speed command strategy made with help of MATLAB documentation and the electric motor speed is increased and decreased with this strategy. And by changing the electric motor speed the simulation results or the parameters are obtained such as electric power, shaft speed, battery and fuel consumptions, speed of the vehicle and the battery losses.

The components used here were an engine which was an ideal spark-ignition engine which has simple parameters, and which has max speed of 7000 RPM and max power is 50 KW. And the Gearbox selected here is a simple gearbox with constant efficiency 95%. The electricity is supplied from the battery where it is stored, and it consists of DC voltage source, internal resistance, current and voltage sensor, the DC voltage source is where the electricity is stored and used, the measure of the battery power is done by the voltage and current sensors. And DC-DC convertor is used is an electric-mechanical device which converts the voltage of DC current from high to low or low to high but here during the power conversion, the voltage is increased because the motor requires more voltage current. and the electric motor is used, it was a block set taken from the MATLAB Simulink library sources, basically this converts the electrical energy to the mechanical rotational energy and vice-versa when the engine powers the motor it changes to the generator and charges the battery. The electric motor and the speed command strategy were made with help of the documentation of MATLAB. The electric motor was commanded with inputs in the speed command strategy to accelerate and deaccelerate accordingly at different step timing.

The wheel which were used here were also a simple tire which doesn’t have any slip, and which were connected by axle to the main driving shaft coming from the transmission. The Vehicle body dynamics were also measured but assumption was made, the slope of road and the wind speed were not considered and set to zero, the vehicle body was used to measure the normal force acting on the wheels and the speed of the vehicle during different performance.

The Speed command strategy here means to give the command to the electric motor to increase or decrease its speed. So here four inputs are given first is to accelerate motor at a given step time 20s and similarly second input command is given to stop acceleration at 70s to get a constant speed of the vehicle and then the vehicle was deaccelerated by giving input at 120s and giving command to stop acceleration at 170s and then the vehicle was running only on the engine. And these all input signal are combined to one signal by integrating them then they are converted to RPM and it are measured by sensors connected
to it for result purpose. And the total duration of the test was 200s and all the parameters such as engine power, battery power, electric power, speed of engine and the electric motor, fuel consumption, etc. were determined by different sensors connected to each component of the simulation. According to some research [3],[4],[5], the comparison between the Parallel Hybrid electric vehicle (PHEV) and the conventional ICE Vehicles (ICEV) were made by collecting the data for every parameter in real world driving of both the vehicle type PHEV and ICEV and compare them. The Software use here was known as Autonomie. The simulation was done on several driving conditions and many real-life parameters were also measured such as weather conditions, accessories load, road pattern, vehicle activity (driving cycle), and engine capability and also fuel economy, emissions, and all equipment performance were evaluated. The standard driving cycles which were used are FTP, UDDS, and US06HWY. According to results, the fuel economy of PHEV was increased up to 68% in real driving condition than the ICEV the reason was due to regenerative braking which was used continuously in city due to which the CO2 and other harmful gas emission decreased up to 40% due using electric mode during less performance required by the vehicle generally in the city traffic. Another benefit was for ECU which can change the power source unit according to required performance, which lead to increase in engine performance by 12% in real world driving cycle whereas in FTP it was 30%.

4. Simulation results

![Vehicle speed Vs Motor speed](image)

Figure 2. Vehicle speed Vs Motor speed

The simulation results we get at 200s step time are the speed of the vehicle and the motor speed as in figure 2. The motor speed is converted from rpm to kmph for comparing it with the vehicle speed. The speed of motor is increasing at 20s constantly with time. The motor powers the wheels of vehicle body that why the speed of the vehicle is also increased gradually with respect to the motor speed. At 70s to 140s the motor has stop accelerating and the vehicle speed is also getting constant, at the 120s the motor decreases its speed to same as the initial speed and the vehicle speed also gets deaccelerated.
The figure 3 above represents the voltage, current and the electric power graph versus time plot. The voltage and current are calculated by ammeter and voltmeter at every time interval, present in battery circuit. The Electric power is measured by product the voltage and current input value, we get the power curve. And as in the graph the power increases at 20s due to acceleration by motor to 20 KW, then motor attends the stable speed so it consume power up to 60 KW and decreases at 140s due to deacceleration and then it shows negative power that means the engine shaft power is also transferred to the motor/generator to recharge its battery and after recharge it gains back 0 KW.

The figure 4 above shows the engine parameters with respect to the time the A) is the fuel consumption as u can see the fuel consumption is increased at 20s up to 0.0006 Kg/s because the vehicle wheels are powered by motor so there is less fuel required than actual amount to accelerate the vehicle by the engine only and then decreases again back to around 0.0002 Kg/s for maintain the vehicle speed. B) is the Power of the engine which is also increased during the acceleration is slightly increased due to some increase of speed of the shaft. And after 140s when the motor stops powering the drive shaft, the power
required by engine is more to charge the battery by supplying rotational power to the motor and the wheels. C) is the throttle graph which is made constant value 0.11.

![Power Curve of Engine and Battery (Motor)](image)

**Figure 5.** Power Curve of Engine and Battery (Motor)

The Figure 5 above shows battery/motor and engine power Vs time, as we know for acceleration the electric motor is only used and engine is to maintain the vehicle speed, so when the acceleration starts the motor starts powering at 20s so it as in figure the motor power is increasing and the engine power has slight changes. The motor decreases after the 140s second because vehicle starts to deaccelerate. Negative curve after the motor stops, in the figure it shows the power that is absorbed by the motor to charge some amount of battery from the rotating engine shaft and some amount of power is gained due to regenerative braking.

![Battery Charge curve](image)

**Figure 6.** Battery Charge curve

![Battery Electrical losses](image)

**Figure 7.** Battery Electrical losses
The figure 6 above shows the battery charge usage and battery losses is shown by the figure above. Figure 6 above shows the battery charge used by the electric motor during the whole process as the acceleration increase the battery charge usage also increases and it used until the deacceleration of the vehicle and then it decreases. The figure 7 above shows battery losses due various reasons, it increases during the acceleration due more current flow and decreases during deacceleration.

5. Conclusion

The simulation of a parallel Hybrid electric powertrain was completed. The method of the simulation was that the engine was powering the wheels to maintain a speed and the vehicle was accelerated and deaccelerate by electric motor, engine was not used to accelerate or deaccelerate. The electric motor was commanded by a speed command strategy and speed controller. The engine was having a constant power due constant throttle. And the power and speed of both engine and motor were determined for 200s step time. The power curves showed that the vehicle has the electrical power which is higher than the engine power and it proves that the vehicle can also accelerate at high speed with only the electric motor. The electric motor also uses the regenerative brake to absorbs some of the power to recharge the battery. And the charging level of battery was also measured with respect to time it also shows that the battery. The charge level also decreases with the time due to increase in motor power and the it also gains some power during the deacceleration due regenerative braking.

The vehicle velocity also increases and decreases as per the figures discussed above with respect to the electric motor acceleration and deacceleration respectively, which shows the output of the simulation as speed of the vehicle. The simulation shows that the vehicle can run on electric motor independently for performance requirement in parallel mode of HEV powertrain. According to studied research [3],[4],[5], it can be concluded that PHEV improves the fuel economy as well as engine efficiency in standard driving cycle as well as real world driving cycle. The improvement in engine efficiency also increased the life span of the engine. Therefore, from all the about research and simulation done it can be stated that the PHEV or HEV has very promising potential solution for improvement of fuel economy than the ICEV conventional vehicles.

6. References

[1] Optimization-Based Control Strategy for Large Hybrid Electric Vehicles-Jianhua Zhou, Mian Li, and Min Xu Shanghai Jiao Tong University, china, 2018.
[2] Energy Management in Plug-in Hybrid Electric Vehicles: Recent Progress and a Connected Vehicles Perspective - Clara Marina Martí nez, Xiaosong Hu*, Dongpu Cao*, Efstathios Velenis, Bo Gao and Matthias Wellers, IEEE, 2016.
[3] A Comparison of Electric Vehicles and Conventional Automobiles: Costs and Quality Perspective, Marek Palinski, 2017.
[4] Study of emissions and fuel economy for parallel hybrid versus conventional vehicles on real world and standard driving cycles, Ahmed Al-Samari, Mechanical and Aerospace Engineering Department Alumni, West Virginia University, 26505, USA, 2017.
[5] How hybrid-electric vehicles are different from conventional vehicles: the effect of weight and power on fuel consumption, C Reynolds and M Kandlikar, 2007.