Analysis of Emission and Fuel Economy in a Plug in Hybrid Vehicle Using Various Control Strategies

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Abstract

Plug-in hybrid electric vehicles (PHEVs) differ from hybrid vehicles (HEVs) with their capability to use off-board electricity generation to recharge their battery. Electric vehicles are highly emerging for transportation purpose, which have been developed over the past several decades due to various environmental concerns. Pure electric vehicles currently do not have adequate range when powered by batteries alone and also recharging of it requires several hours. The shortcoming raised with the standalone energy source powered electric vehicle made to think about an alternative option for an electric vehicle and motivated towards the hybridization of energy sources in electric vehicle. This paper analyzes the equivalent power circuit and operation principles of a PHEV using UDDS and NEDC driving pattern. Regenerative braking also provides an effective way of extending the driving range of battery powered electric vehicles. Conventional automobiles use Internal Combustion Engines (ICEs) to operate with the energy source from fossil fuels. However, the conventional vehicle system provides limited fuel economy, as well as producing harmful air pollutants. A Plug-in Hybrid Electric Vehicle (PHEV) has been introduced which operates within its all electric range. Which have high capacity of energy storage system. PHEVs used to charge the battery from electricity grid, which differs from the traditional Hybrid Electric Vehicles (HEVs). The plug in hybrid electric vehicle is instigated for enhancing the vehicle performance by improving the fuel economy, effectively capturing the regenerative braking energy by controlling the Battery State of Charge (SoC) level within the optimal upper and lower bound that would improve the battery life, eliminating the fuel starvation problem and maximizing the drivability of the vehicle through an optimized distribution of the required power to the load. The proposed work is focused on designing a gasoline based Hybrid Electric Vehicle includes the modelling of hybrid energy sources and other interfacing structures.

Keywords: *Electric vehicles, battery, transportation, hybridization, hybrid energy*

INTRODUCTION

The energy dependents and climate change have become increasingly serious issues, with the emergence of energy crisis. The various ways of reducing air-pollution have become the great challenge, which leads to promoting research on and applications of reducing the emission and energy consumption in the automobile industry. Conventional vehicles consume considerable amounts of fuel, which produces exhaust gases and environmental pollution during different driving cycles [1–5]. Therefore, prospective vehicle designs favour improved exhaust emissions and energy consumption without compromising vehicle performance. Hybrid Electric Vehicles (HEV) provide improved fuel economy due to extra degree's of freedom provided by battery energy storage and one or more electric machine's which allow running a smaller combustion engine in a higher efficiency region. The battery storage also enables capturing the braking energy, which is wasted as heat in conventional vehicles. Among possible configurations of a hybrid electric power train, power-split or parallel-series which provides both series and parallel functionality are produced by several auto-makers [6–8].

Compared with Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs) have ability to use off-board electricity generation to recharge the battery. In addition to possessing charge-sustaining HEV operation capability, PHEVs use the stored electrical energy from the battery during a charge depletion period to displace a significant amount of fuel consumption [9, 10].

HYBRID VEHICLES DRIVE TRAINS

As the name expresses, hybrid vehicles get benefit of minimum two energy sources. The demanded power for traction and other auxiliary loads in the vehicle is shared between two sources of energy with a specific power sharing management. The main parts of each hybrid vehicle could be classified as:

- Primary energy storage system.
- Secondary energy storage system.
- Primary energy converter.
- Secondary energy converter.
- Control system.
- Transmission.

There are different topologies of hybrid vehicles but series and parallel topologies are the most commonly used ones. Hybrid electric systems can be broadly classified as series or parallel hybrid systems. In series hybrid systems, all the torque required to propel the vehicle is provided by an electric motor. On the other hand, in parallel hybrid systems, the torque obtained from the heat engine is mechanically coupled to the torque produced by an electric motor. In an electric vehicle, the electric motor behaves exactly in the same manner as in a series hybrid. Therefore, the torque and power requirements of the electric motor are roughly equal for an electric vehicle and a series hybrid, while they are lower for a parallel hybrid.

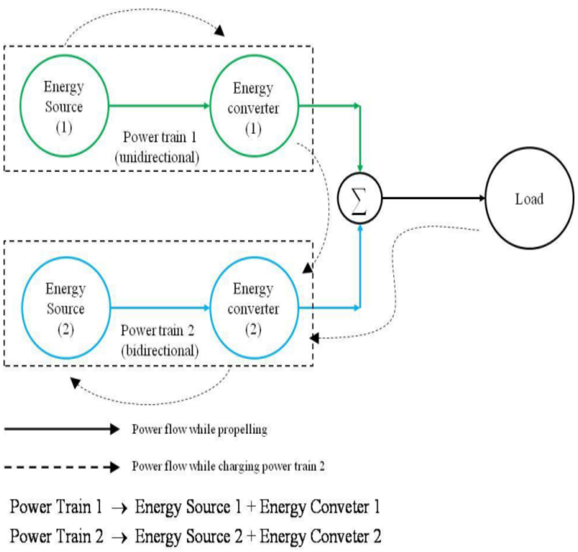

Fig. 1: *HEV Configuration.*

Each topology has its own drive train and components. It also has its own advantages and disadvantages and uses different control strategies [11, 12].

METHODOLOGY

A Plug in Hybrid Electric Vehicle (PHEV) contains three major parts: the power battery pack (usually in series as an energy-storage unit), the driving motor and the power converter controller. The performance of based on optimization methods is closely related to the quantity of trip information available in the form of road profiles, velocity profiles, trip distances, and weather conditions. The trip information of the driving cycle in a practical application is difficult to obtain detail, even though modern vehicular navigation systems are utilized for various applications. In this project, three basic PHEV operation modes involved are:

- Pure Electric Driving (PED).
- Hybrid Driving Charge Depleting (HDCD).
- Hybrid Driving Charge Sustaining (HDCS).

These are defined based on the battery state of charge (SoC) profile. Three different PHEV energy management strategies without considering the detailed information of trip distance and driving cycle, which is combined with two or three basic modes of operation are developed and comparatively examined based on simulation models [13– 15].

INTERFACING STRUCTURE AND MODELING OF PLUG IN HYBRID ELECTRIC VEHICLE

Once the analytical approaches have finished regarding each component used in a typical hybrid drive train it is required to make a model for any of the components in simulation area. All the components including battery, engine, electric motor and generator, vehicle dynamics, tyre, automatic driver, driving cycles and control system are modelled in MATLAB/Simulink. In the following, the modelling process in MATLAB for each part is explained. Normally the vehicle traction system consists of three main components, one is the energy sources, second the power electronics converters and the other component is the transmission system. The main use of source in the vehicle traction system is to provide the supply for the load demand [16, 17].

The power electronics converters are needed to stabilize the source output due to the fact that the output of the source is a varying one because of chemical reactions inside the source. In this project, both the engine and the motor provide traction power to the wheels, which means that the hybrid power is summed at a mechanical node to power the vehicle. As a result, both of the engine and the motors can be downsized, making the parallel architecture more viable with lower costs and higher efficiency. This project also incorporates the DC-AC bidirectional converter modelling since the traction motor used here is of AC one. Also, the vehicle transmission system incorporates the two components such as traction motor and the vehicle dynamics in the transmission system. The vehicle control unit controls entire energy flow in the vehicle system operation. The overall block diagram representation of the Plug in Hybrid Electric Vehicle is shown in Figure 2.

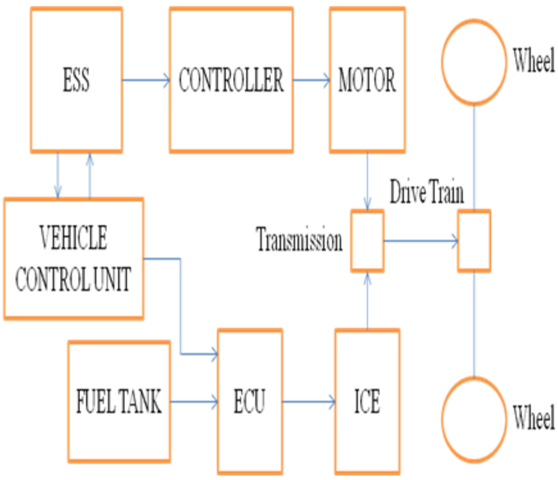

Fig. 2: *Block Diagram of Plug in Hybrid Electric Vehicle.*

In this paper modelled Plug in Hybrid Electric Vehicle is shown in the Figure 7. The driving cycle provides the reference speed which is compared with actual speed from the vehicle system through the driver model. The driver model generates torque command to run the vehicle system. Then the corresponding performance of the entire system can be verified through the waveforms [18–20].

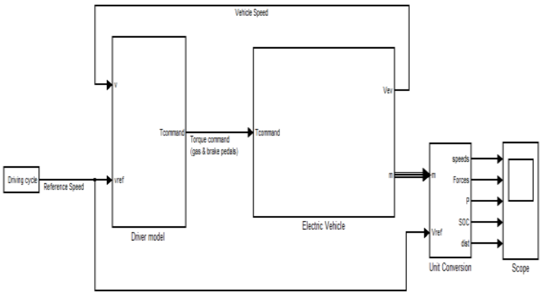

Fig. 3: *SIMULINK Model for Electric Vehicle.*

It is mandatory to impose the drive cycle on the proposed model. A driving cycle is a standardized driving pattern that described by means of a speed time table. Therefore, the speed and the acceleration are known for each point of time and the required mechanical power as a function of time can be determined for the proposed vehicle. Driving cycles are produced by different countries and organizations to assess the performance of vehicles in various ways, as for example energy storage module life span and energy sources sizing. In this work, two different drive cycles such as NEDC (New European Driving Cycle) and UDDS (Urban Dynamometer Driving Schedule) is presented for investigating the performance of the proposed electric vehicle model.

The NEDC cycle is a rather simple pattern consisting of periods of constant acceleration, constant deceleration and constant speed. This cycle, however, is not a true resemblance of actual driving conditions in an urban scenario. It is presented here, as these are standards with which European car manufacturers have to refer when stating their vehicle’s performance in terms of achievable range and emissions. On the other hand, the next drive cycle used to assess the performance of the proposed vehicle model is the UDDS drive cycle which is derived from actual urban driving data which exhibits continuously varying speed over the entire driving cycle with the maximum range of 45 km/hr. The UDDS drive cycle is used to simulate the urban/city driving of a vehicle that providing frequent start and stops.

RESULTS FOR UDDS DRIVE CYCLE

The power consumption by the standalone battery driven electric vehicle is presented in the following section. Once the vehicle accelerates, the torque of the motor is maximum as the speed reaches the maximum speed. In the cycle, the acceleration is zero so the motor power suddenly decreases because it does not have to overcome the inertia of the vehicle and accelerate the total weight of it. It can also be seen that during the deceleration the power is negative which indicates that energy is being fed back to the motor to charge the batteries. The results obtained for the simulation of Plug in Electric Vehicle is discussed in the following section.

The speed generated by the vehicle should meet its reference speed and which also acts like a closed loop operation. The speed profile generated by using UDDS Drive Cycle is shown in the Figure 4.

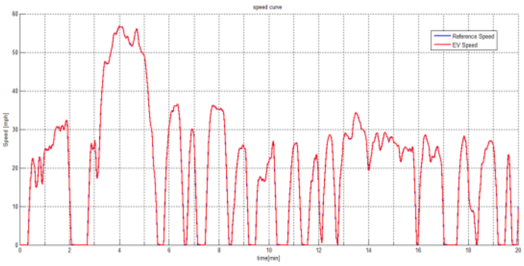

Fig. 4: *Speed Profile for UDDS Drive Cycle.*

The vehicle system generated drive force for vehicle acceleration which should also take in account with resistive forces (Aerodynamic Force, Grade Force, Rolling Resistance Force). The force generated using UDDS Drive Cycle is shown in the Figure 5.

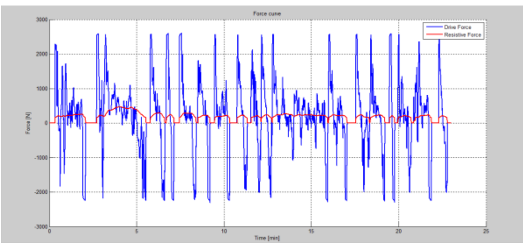

Fig. 5: *Force Required to Drive the Vehicle System.*

The PMAC motor modelled here is a static one, contains the three phases current and the speed of the vehicle as the inputs and the power and the torque developed as the output. The Power Required to Drive the Vehicle System using UDDS Drive Cycle is shown in the Figure 6.

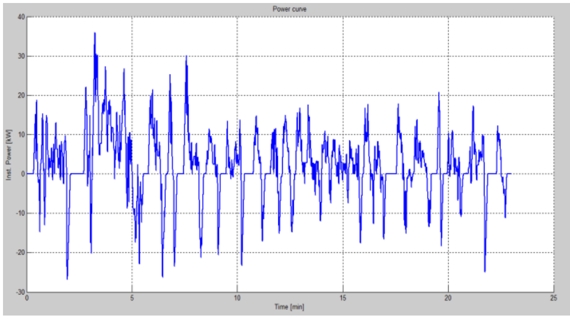

Fig. 6: *Power Required to Drive the Vehicle System.*

The inverter input current and battery output current were noted to obtain the relation. The current output profile at the DC-DC converter terminals for UDDS Drive Cycle is shown in the Figure 7.

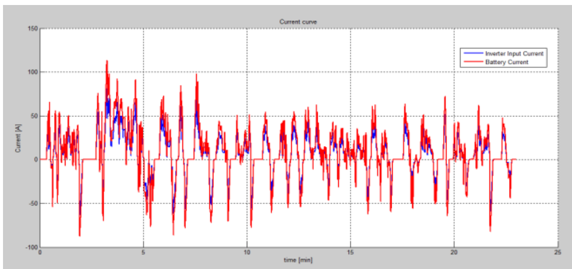

Fig. 7: *Current Output Profile at the DC-DC Converter Terminals.*

The SoC of the battery were noted while charging and discharging according to UDDS Drive Cycle. SoC Profile of the

Battery for UDDS Drive Cycle is shown in the Figure 8.

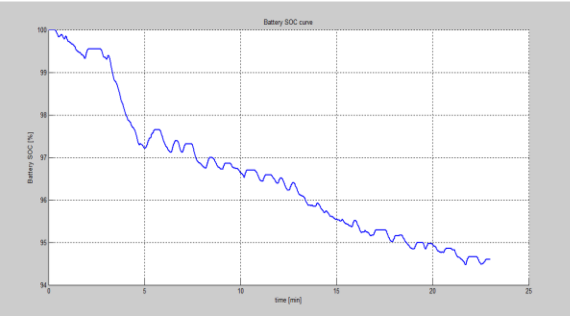

Fig. 8: *SoC Profile of the Battery for UDDS Drive Cycle.*

The distance travelled by the vehicle should be noted according to the UDDS Drive Cycle pattern with respect to time. The travelled profile using UDDS Drive Cycle is shown in the Figure 9.

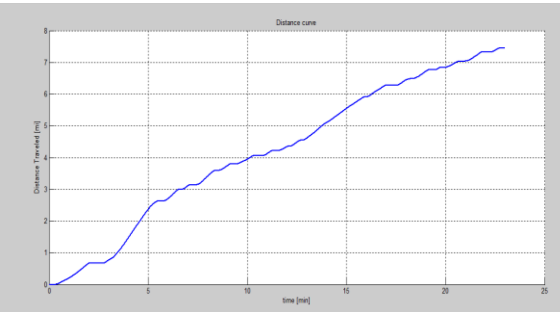

Fig. 9: *Vehicle Distance Profile for UDDS Drive Cycle.*

RESULTS FOR NEDC DRIVE CYCLE

The performance of Electric Vehicle components including traction motor and battery is analyzed by using another drive cycle called NEDC (New European Driving Cycle). The NEDC cycle is a rather simple pattern consisting of periods of constant acceleration, constant deceleration and constant speed. This cycle, however, is not a true resemblance of actual driving conditions in an urban scenario. It is presented here, as these are standards with which European car manufacturers have to refer when stating their vehicle's performance in terms of achievable range and emissions. The Plug in Electric Vehicle results for NEDC drive cycle results are shown as follows.

The speed generated by the vehicle should meet its reference speed and which also acts like a closed loop operation. The speed profile generated by using NEDC Drive Cycle is shown in the Figure 10.

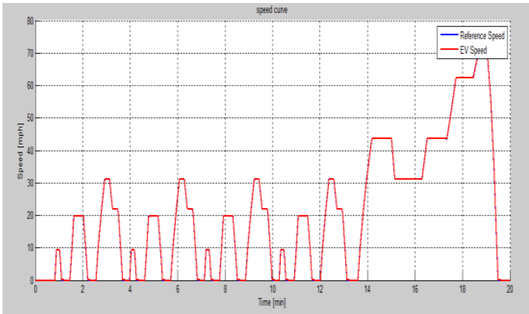

Fig. 10: *Speed Profile for NEDC Drive Cycle.*

The vehicle system generated drive force for vehicle acceleration which should also take in account with resistive forces (Aerodynamic Force, Grade Force, Rolling Resistance Force). The force generated using NEDC Drive Cycle is shown in the Figure 11.

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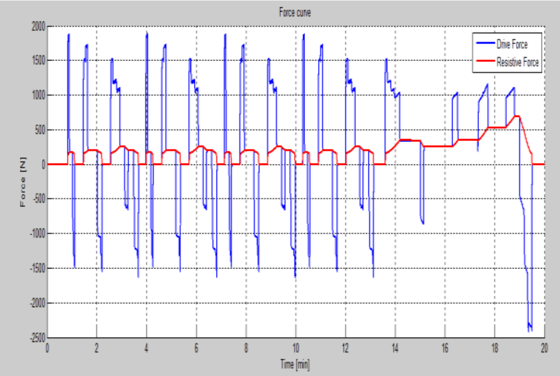

Fig. 11: *Force Required to Drive the Vehicle System.*

The PMAC motor modelled here is a static one, contains the three phases current and the speed of the vehicle as the inputs and the power and the torque developed as the output. The Power required to drive the Vehicle System using NEDC Drive Cycle is shown in the Figure 12.

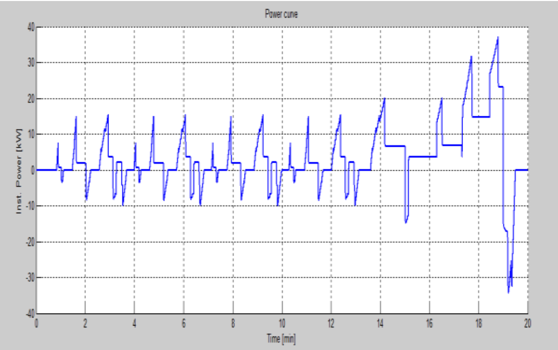

Fig. 12: *Power Required to Drive the Vehicle System.*

The inverter input current and battery output current were noted to obtain the relation. The current output profile at the DC-DC converter terminals for NEDC Drive Cycle is shown in the Figure 13.

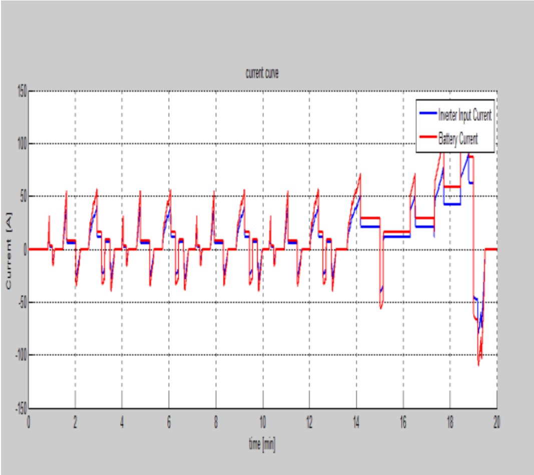

Fig. 13: *Current Output Profile at the DC – DC Converter Terminals.*

The SoC of the battery were noted while charging and discharging according to NEDC Drive Cycle. SoC Profile of the Battery for NEDC Drive Cycle is shown in the Figure 14.

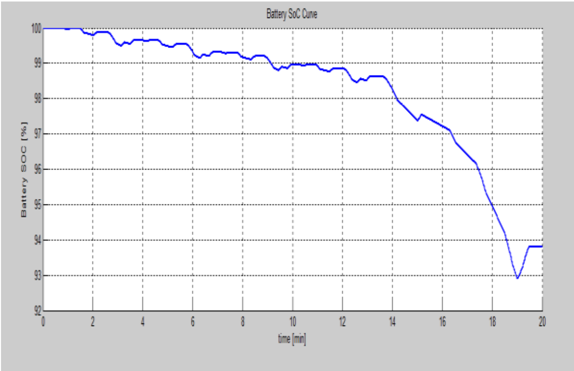

Fig. 14: *SoC Profile of the Battery for NEDC Drive Cycle.*

The distance travelled by the vehicle should be noted according to the NEDC Drive Cycle pattern with respect to time. The travelled profile using NEDC Drive Cycle is shown in the Figure 15.

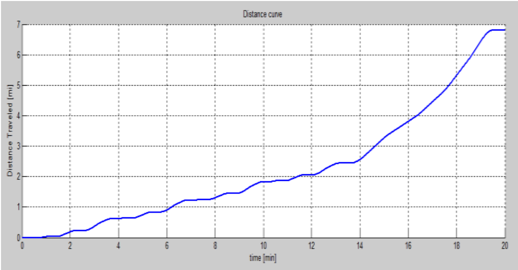

Fig. 15: *Vehicle Distance Profile for NEDC Drive Cycle.*

A standalone Electric Vehicle was modelled and its systematic model was built for energy flow analysis. Two popular drive cycles New European Drive Cycle and Urban Dynamometer Driving Cycle is used to test the vehicle performance. Results obtained from the simulation model are clearly shows that the model developed provides the exact performance of the vehicle.

CONCLUSION

The PHEV configuration combines the benefits of electric vehicles (high efficiency) and of petrol-based vehicles (high level of autonomy). Regarding the significant role of modelling and simulation in the design process of hybrid vehicles, the principles of simulation and some modelling methods were introduced. In order to create a standalone battery driven vehicle, different components in the series drive train including vehicle dynamics, battery, electric machine, driver, tyre and energy management and control system were modelled. The dynamics of the vehicle were discussed and based on these dynamics; a systematic model of standalone battery driven vehicle for its energy flow analysis in Simulink/MATLAB was developed. Two popular drive cycles (NEDC cycle, UDDS cycle) are used to test the vehicle performance. Results obtained from the simulation model are, the power delivered and power required by the vehicle, force required to drive the vehicle, distance covered by the vehicle, torque required to drive the vehicle and state of charge of the battery. The obtained results clearly show that the model developed provides the exact performance of the vehicle.

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