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Performance Evaluation of Energy Storage Systems for Different Drive Cycles in Hybrid Electric Vehicle

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ABSTRACT

The important control parameters for the hybrid electric vehicle are the lower and upper limit of state of charge (SOC). The vehicle's onboard energy system defined the fuel economy and the electric range thus during the period at which the power demand is less, we will allow the ESS to get charged and they will get discharged during the period of high-power demand. ESS acts as the catalysts as they help in boosting the energy requirements. In HEVs, maintaining high energy density is a necessity while demanding higher peak power as well thus this results in doubling the incremental cost of the vehicle if approx. 15 % of all electric range is demanded. The SOC of the vehicle directly affects the economy and the emission rates. In this work the parallel HEV is modelled by using ADVISOR and Different SOC limits are taken for testing the performance and fuel economy for the same designed driving cycle. With the simulation results we will be able to specify best upper and lower limits of SOC such that vehicle will achieve best fuel economy and emission performance. The simulation is performed by taking repetitive velocity profiles (drive cycles) of four different curves i.e. UDDS, ECE, FTP and HWFET. The SOC and emission curves are observed for these different drive cycles and the results having emission rates for HC, CO and NOx (in g/miles) are tabulated.

Keywords: *SOC; Energy Storage System; Hybrid Electric Vehicle; Fuel Economy; Advisor: Drive Cycle.*

1.0 Introduction

The ESS of most commercially available HEVs is made up entirely of battery packs coupled to a high-voltage dc bus by a bidirectional converter. In electric vehicles, ESS should be able to meet the vehicle's entire power consumption and thus in order to enhance the range of electric vehicles, the battery pack's capacity must be increased to store enough energy. To enhance miles per gallon efficiency, topologies to hybridise ESSs for EVs, HEVs, FC hybrid vehicles (FCHVs), and PHEVs have been designed by several authors. Commercially accessible HEVs with efficiency of around 40 miles per gallon include the Toyota Prius, Honda Insight, and Ford Escape.

Hybrid electric vehicles offer extra flexibility in order to improve fuel economy and emissions [1]. For the HEV, the electrical energy storage is coupled with an electric motor so that the vehicle can operate efficiently. The two power path, which is possible due to coupling of bidirectional converter, makes it possible to shut down the engine during low power operation and also the more efficient and smaller engine can be used for this type of vehicle. This can be done while maintain the vehicles average power carrying capability [2].

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During this process the electrical energy in the battery or any other energy storage system is maintained by accepting the excess power during the efficient operation of engine. The process of regenerative braking in which the kinetic energy is stored in the form of electrical energy, also helps to charge the energy storage system [3]. Batteries are one of the most often used ESS. However, a battery-based ESS faces a number of obstacles, prompting researchers to seek alternative methods. In battery-based ESSs, the battery's power density must be sufficient to fulfil the peak power demand.

Currently, the most prevalent solutions for vehicle ESSs are batteries and ultracapacitors (UCs). The majority of onboard electric energy is stored in batteries, which have high energy densities. UCs, on the other hand, have high power densities, great efficiency, long life cycle, and a quick charging/discharging response. Energy density, power density, lifetime, cost, and maintenance are all essential properties of automotive ESSs [4]-[5]. A fuel cell (FC) is another renewable energy source, although its performance on cars is limited due to its long time constant. Currently, no single energy storage system can cover all of the needs of HEVs and electric vehicles (EVs).

For control and energy management, the most important factor which needs to be taken into concern is the state of charge value for the battery. Practically 20 % to 80% is the range which is usually set for the state of charge constraint [6]. The lower and upper limit of the SOC is used to start and stop the battery charging respectively.

In this paper we will study that how the different parameters such as state of charge, fuel economy and emissions are interrelated and affect each other [7]. With the help of this study, we can easily estimate that what can be the best state of charge value for achieving the better performance of the vehicle in terms of fuel economy and reduced emissions.

2.0 Energy Storage Systems

2.1 Li-ion batteries

The electrolyte in Li-Ion is a lithium salt dissolved in an organic solvent. Low memory effect, high specific power of 300 W/kg, high specific energy of 100 Wh/kg, and extended battery life of 1000 cycles are all promising features of Li-ion batteries. The lithium-ion battery is recyclable, performs well at high temperatures, and has a high energy density [8]-[9]. Because of these excellent features, lithium-ion batteries have a good chance of replacing NiMH batteries as next-generation automotive batteries.

2.2 Lead -acid batteries

For HEV applications, the lead–acid battery has various advantages. They are currently being produced in large quantities, resulting in a relatively low-cost power source. Furthermore, due to its widespread use over the past 50 years, lead–acid battery technology is a mature process. The battery's negative active material is spongy lead, the positive active material is lead oxide, and the electrolyte is diluted sulfuric acid [8]-[9]. The battery's life cycle would be reduced if it was operated at a high rate of state of charge (SOC). Both positive and negative materials are converted to lead sulphate for discharge. on the other hand, it is not appropriate for discharges exceeding 20% of its rated capacity.

2.3 Nickel-metal hydride batteries

The NiMH battery has double the energy density of a lead–acid battery. NiMH components are non-toxic to the environment, and the batteries may be recycled. The electrolyte in a NiMH battery is an alkaline solution and the positive electrode of a NiMH battery is nickel hydroxide,

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whereas the negative electrode is a designed alloy of nickel, titanium, vanadium and other metals[9]-[10]. The NiMH battery is safe to use at high voltage and offers a number of benefits, including the ability to store volumetric power and energy, a wide operating temperature range, long cycle life and resistance to discharging and overcharging.

2.4 Ultra -capacitors

An insulator separates two parallel plates on which the charges are stored in Ultra Capacitors. The positive electrode's applied potential draws negative ions in the electrolyte, whereas the negative electrode's applied potential attracts positive ions. Because the electrodes have no chemical changes, UCs have a long cycle life but a poor energy density. Low internal resistance provides UCs tremendous efficiency, but if the UC is charged at a very low SOC, it can cause a big burst of output currents. Researchers are looking into several ways to expand the surface area of the electrodes in order to improve the energy storage capacity of UCs even more. Low internal resistance provides UCs tremendous efficiency, but if the UC is charged at a very low SOC, it can cause a big burst of output currents [9]-[10]. Because the charges are physically stored on the electrodes, the power density of the UC is far higher than that of the battery.

2.5 Fuel cells

During Reactants enter the cell during the creation process, whereas reaction products exit the cell. As long as the reactant flows are kept up, the FC can produce power. The FC reacts in the electrolyte and produces electricity from the fuel on the anode and the oxidant on the cathode. For FCs, a variety of oxidants and fuels can be used. Since hydrogen has the highest energy density of any fuel and the only byproduct of cell reaction is water, it is the ideal non-polluting fuel for FCs.

3.0 Model Description

The parallel hybrid electric vehicle model is taken and the parameters are illustrated in the below given table-

Table1: Vehicle Parameters Used for Simulation

Vehicle weight	15000 Kg
Motor ratings(power)	43 KW
Torque	200 nm
Engine ratings	120 hp
Battery pack	VRLA
Battery capacity	110 Ah
Terminal voltage	145 V

3.1 Driving cycle

In order to make the study more reasonable, the different five types of drive cycles are taken here which are shown graphically in the figures. These cycles are taken in the repetitive sequence so that the total simulation time can be long enough to test system properly and the differences can be observed significantly [12].

The velocity profile of the four velocity profiles i.e. UDDS, ECE, FTP and HWFET are specified in the following below figures – fig.1, fig.2, fig.3 and fig.4 respectively.

Figure 1: UDDS Drive Cycle

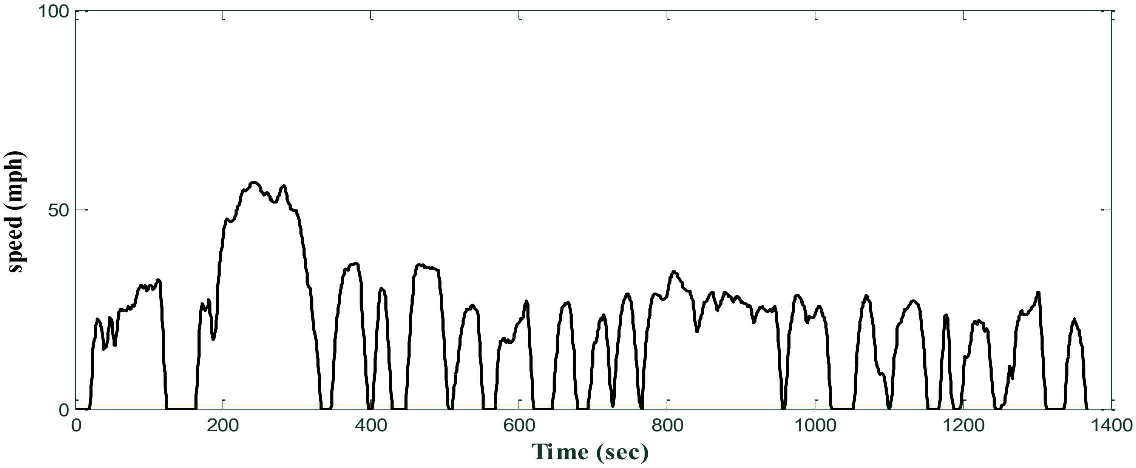

Figure 2: ECE Drive Cycle

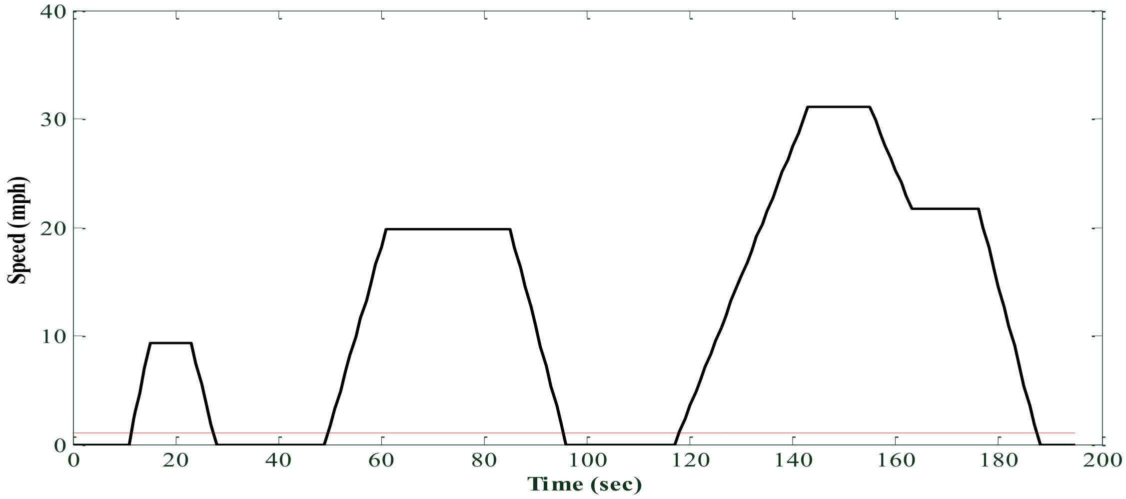

Figure 3: FTP Drive Cycle

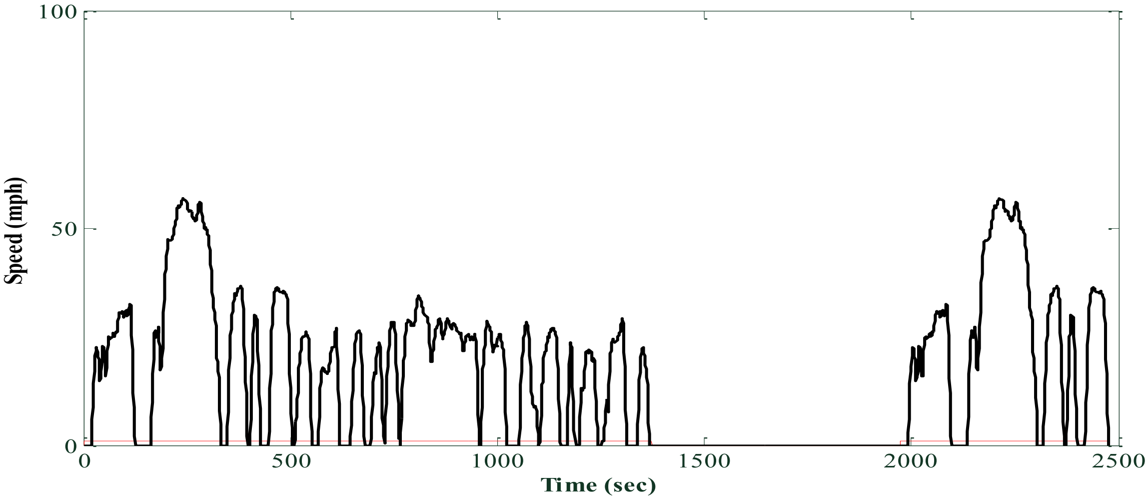

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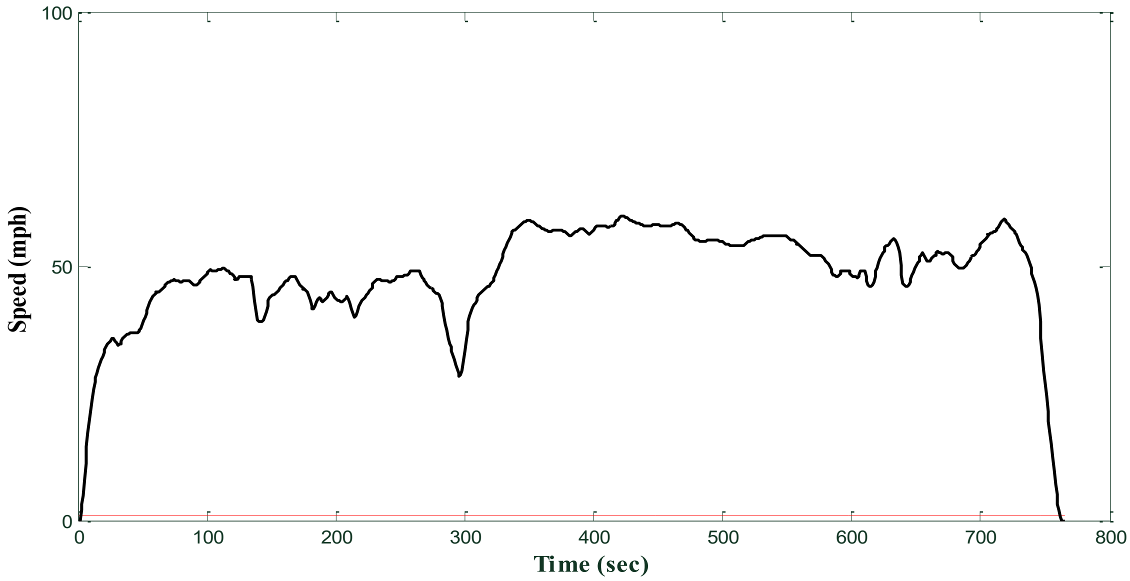
Figure 4: HWFET Drive Cycle



4.0 Simulation Results

The simulation is done in two different parts, one is done for the lower limit of SOC and the second is done for the upper limit of SOC .it is required to maintain the practical limits of 20 % to 80% as the too lower or too higher value of SOC can damage the battery. For the upper limit i.e. at the end point the groups are formed, the simulations are performed separately and we will try to find the best soc range for each group.

The engines operating process and the total consumption of fuel are the two important factors which are taken into concern as it depends on the initial values of SOC. For data processing here we are following the process through which we can easily compare results within the same groups or the different groups. Some parameters which are noted after each simulation are as follows- fuel consumption for finding fuel economy and CO, HC, NOx for emissions. In results the data will be tabulated so that it will be easier to analyse it easily and properly.

Table 2: Group of Data Having Minimum Fuel Consumption

Group	Lower (SOC)	Upper (SOC)	Fuel consumption	CO (g/miles)	HC (g/miles)	NOx (g/miles)
1	20	40	min	max	min	max
2	30	50	min	max	min	max
3	40	60	min	max	min	max
4	50	70	min	…..	min	max
5	60	80	min	max	min	max
6	70	80	min	…..	min	max
7	80	85	min	max	min	max

From the above table, we can infer that

- The group in which the range of SOC is 20 i.e. for groups 1, 2,3,5,7, the best fuel economy is achieved.

- Mostly when the HC mass is minimum, the NOx mass is maximum.
- CO mass is maintained maximum for most of the groups.

The state of charge (SOC) variations and the emissions including (HC, CO, NOx) are illustrated in the below figures for the four different velocity profiles.

Table 3: The Usable SOC Range of Different ESS

ESS	Capacity	Usable SOC
Li-ion	12	20%
Shin Kobe	4	18%
Saft	12	20%
Lead Acid	25	28%
Ni-MH	14	30%
Panasonic	6.5	40%
ovonic	12	30%

5.0 Conclusion

In this study as the state of charge parameter for the four different drive cycles is taken into account to test the simulation results which are performed in series. Energy storage devices got the charge when the power demand is low and during high demand of power it gets discharged. The ESS is the factor on which the electric range and fuel economy is dependent. Currently, the most prevalent solutions for vehicle ESSs are ultra - capacitors and batteries. The majority of onboard electric energy is stored in batteries, which have high energy densities. UCs, on the other hand have high power densities, quick charging/discharging reaction, great efficiency and long-life cycle.

In ground vehicles, batteries are the principal ESS. Increasing the AER of cars by 15% nearly doubles the ESS's added cost. This is because the ESS of HEVs maintains a high energy density while necessitating a higher peak power. A fuel cell (FC) is another renewable energy source, although its performance on cars is limited due to its long time constant. Currently, no single ESS can cover all of the needs of HEVs and electric vehicles (EVs).

The state of charge and the emissions for these four different cycles are shown with the help of obtained results. By observing the study performed and the simulation results we can infer that –

- If we have the minimum HC mass then NO x mass must be max. then this group of SOC range will achieve best fuel economy.
- It is also observed that for a fixed velocity profile the best fuel economy can be achieved by the SOC range which is same for different groups

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