Effects of engine sizing on battery state-of-charge for hybrid electric vehicle

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ABSTRACT – The purpose of this study is to investigate the effects of engine sizing on battery state of charge (SOC) for hybrid electric vehicle (HEV). It is carried out by using ADVISOR software, in which the vehicle system is simulated based n US06 driving cycle to represent both highway and city driving. The battery parameters are kept constant and 3 different sizes of engine are used. The optimum engine size obtained from the simulation is 36 kW. The engine manages to charge the battery at considerable rate and the battery SOC is 0.46 at the end of the simulation. All the engine sizes manage to propel the vehicle following the US06 driving cycle. But, smaller engine size causes the battery to deplete excessively below 15 % of SOC and larger engine size causes the battery to overcharge.

1 INTRODUCTION

Automotive industry is moving towards producing vehicles equipped with powertrain system that able deliver the best fuel consumption. The ideal approach is by having powertrain system that is totally independent of fossil fuel source, which is the electric vehicle. The immaturity of battery technology forces industrial players to come out with mid-term solution. Currently, hybrid electric vehicle is the best approach of having better fuel consumption vehicle.

Hybrid electric vehicle consists of several major components such as internal combustion engine (ICE), battery, generator and electric motor. Each of these components needs to be sized properly to ensure the vehicle meets the required performance characteristics. The size of two power sources of the vehicle, which are the ICE and battery needs to be determined in the initial stage of vehicle development. It is because, both of these power sources are inter-dependent in propelling the vehicle. ICE is the main source of energy to charge the battery other than by utilizing the regenerative braking.

The objective of this study is to investigate the effects engine sizing in battery SOC. Improper size of engine causes the battery to deplete excessively during used or overcharge. Both conditions are not good to preserve the battery life and also decrease the optimum performance of the battery.

2 RESEARCH METHODOLOGY

2.1 Vehicle parameters

This study is conducted by using simulation approach. ADVISOR software is used to investigate the battery performance of the vehicle. The type of vehicle chosen for this study 5-door passenger car, which is the typical type of HEV currently in the market. The required vehicle performance is shown in Table 2.1.

Table 2.1 Desire vehicle performance

Acceleration (0-60 mph)	Top Speed	All-electric range	Gasoline-only fuel economy
8 sec	95 mph	40 miles	50 mpg

For the purpose of this study, Li-ion battery is used and the battery parameters are set to be constant. The details of battery are shown in Table 2.2.

Table 2.2 Battery Specifications

Type	Cylindrical
Capacity (Ahr)	89.8
Voltage (V)	362
Energy (kWhr)	32.5
Weight (kg)	157.8
Volume (dm^3)	122.4
No of cells	4000
No of modules	200

The investigation is carried out by using 3 different engine sizes which are 25 kW, 36 kW and 40 kW. All these engine specifications are obtained from ADVISOR software.

2.2 Simulation

The simulation is carried by using US06 driving cycle. This driving cycle is chosen because it is able to represent both highway and city driving. It is run for a total of 12 cycles for each engine size. The initial battery SOC is at 0.3 or 30 %.

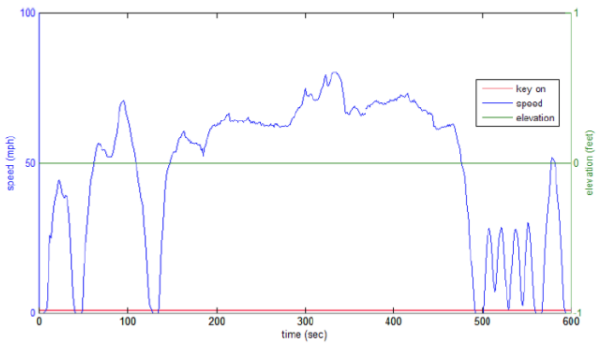

Figure 2.1 US06 Driving Cycle

3 RESULTS AND DISCUSSION

In this section, the behavior of battery SOC due to engine sizing is discussed in detail. Firstly, the simulation was run by using 25 kW engine. The results of simulation are shown in Figure 3.1 below. The simulated vehicle could meet the required speed by following the US06 driving cycle. It indicated that, both power sources of the vehicle, engine and battery could provide enough power to propel the vehicle. But, battery SOC was continuously depleting. The engine did not have the capability to charge the battery during the simulation process. Battery SOC went below 15 % at the end of simulation. When the engine size of 40 kW was used, it overcharged the battery to be over 80 %.

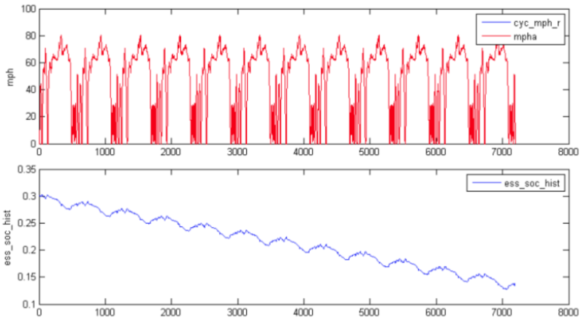

Figure 3.1 US06 Driving Cycle and Battery SOC for engine 25 kW

The optimum engine size obtained from the simulation is 36 kW and the simulation results are shown in Figure 3.2. It was achieved by having lower limit of engine size of 20 kW and upper limit of 40 kW based on previous simulation results. The results showed that both power sources of the vehicle, engine and battery were able to deliver enough power to propel the vehicle by following the US06 driving cycle. The battery SOC was not depleting and the engine was able to charge the battery at considerable rate. By the end of simulation, battery SOC is at 0.47 or 47 %.

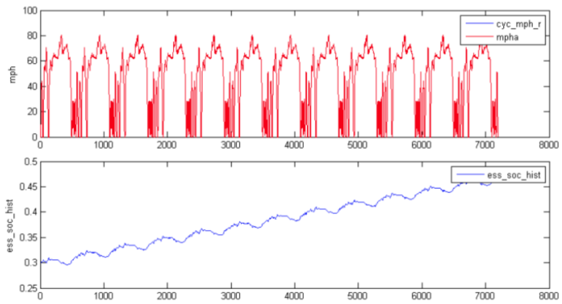

Figure 3.2 US06 Driving Cycle and Battery SOC for Engine 36 kW

Even though the charging process of battery can be controlled by implementing proper control strategies, but engine sizing is very important particularly in the early design stage of HEV. For this simulation, it showed that the vehicle powertrain system could provide enough power in fulfilling the vehicle performance requirements. The vehicle could meet the required speed of US06 driving cycle but improper engine sizes could not charge the battery effectively. The small engine size was not able to charge the battery and when the vehicle was travelling at longer distance, the battery was going to be totally depleted. This vehicle was depended only on engine to propel the vehicle and the electric drive system became useless. Vehicle fuel consumption was going to suffer if this condition occurred. On the other hand, bigger engine size was overcharging the battery. Furthermore, the excessive energy from the engine was going to be wasted and not fully utilized for this vehicle system. Bigger engine size was more expansive and it increased the total cost of the vehicle.

It is also important to note that battery charging process is very critical in preserving the battery life. For HEV, there are lower and upper SOC limits that have been set to avoid undercharge and overcharge. If the battery is depleting and charging exceeding these limits, it will tremendously shorten the battery life.

SUMMARY

This study was performed to investigate the effects of engine sizing on battery SOC for HEV. ADVISOR software was used to determine the behavior of battery SOC on various engine sizes. Simulation was run by using US06 driving cycle to represent both highway and city driving. All the engine sizes were able to meet the change of required speed by following US06 driving cycle. The results also showed that the optimum engine size for this vehicle is 36 kW. By having lower engine power such as 20 kW as in the simulation caused the battery SOC to drop below 15%. Engine power of 40 kW caused the battery to overcharge exceeding the upper limit. Both conditions can jeopardize the battery life. Because of that, optimum engine size is very important for HEV. It has to satisfy both vehicle performance requirements and also charging the battery within the allowable limits.

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