A PERFORMANCE COMPARISON STUDY AMONG CONVENTIONAL, SERIES HYBRID AND PARALLEL HYBRID VEHICLES

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ABSTRACT

The aim of this study is to compare the energy consumption and performance criteria of conventional vehicle with series hybrid vehicle and parallel hybrid vehicle those contain different traction systems. For this purpose, ADVISOR simulations have been conducted and the results have been compared with each other.

INTRODUCTION

Hybrid electric vehicles(HEV), that make contributions to the reduction of air pollution, to the reduction of fuel consumption and to the reduction of the dependence on imported oil, are well on the way to become an alternative for the conventional internal combustion engine vehicle.

A hybrid vehicle has a powertrain in which propulsion energy can be transmitted to the wheels by at least two different energy conversion devices (e.g. internal combustion engine, gas turbine, electric motor, hydraulic motor, fuel cell) drawing energy from at least two different energy storage devices (e.g. fuel tank, battery, flywheel, supercapacitor, pressure tank etc.)[1]. Energy management systems in hybrid electric vehicles aim to fulfill maximum fuel efficiency, minimum emissions and best driving performances [2]. Electric motors used in HEV have to have high instantaneous power, high power ratio, wide speed range, high torque at starting speed, high efficiency and robustness to operate at various conditions [3].

In this study, the comparison has done for a passenger car. The traction system has chosen conventional, series hybrid and parallel hybrid. It is not aimed to design a new vehicle wholly. While designing a new vehicle, the performance targets should be determined that the vehicle should meet and the calculations should be done for the required traction system in order to meet the determined performance criteria. The calculation results give the power values of system elements for conventional, series hybrid and parallel hybrid traction systems, which show the differences among them. At this position, different vehicle designs will be performed which meet the same performance targets. And the only comparison criteria will be the fuel consumption [4].

SIMULATION

In this study, only the traction system in a conventional passenger car is replaced by a series hybrid and a parallel hybrid traction system consequently. The performance variance caused by the traction system, the advantages and disadvantages of traction systems are determined. In order to make the comparison equally, only the traction system elements are changed on the same car and the power of the traction system elements are equalized at each different concept. ADVISOR is used for simulations to make the comparison. [1]

At this comparison, the same passenger car is used as a base to change the traction system. The details of the vehicle are shown below.

Curb weight	: 592 kg
Air drag coefficient	: 0.335
Frontal area	: 2 m^2
Wheel diameter	: 0.65 m
Wheel friction coefficient	: 0.01

Different traction systems are put on this passenger car. The vehicles that have different traction systems are

- Internal Combustion Engine Vehicle (ICEV)
- Series Hybrid Electric Vehicle (SHEV)
- Parallel Hybrid Electric Vehicle (PHEV)

The schematic diagrams of ICEV, SHEV and PHEV are given consequently in Figure 1, Figure 2 and Figure 3.

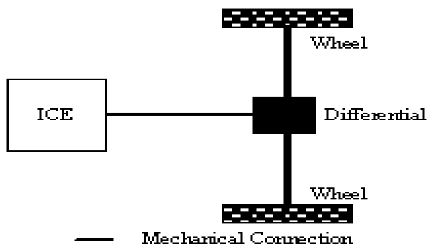

Figure 1. Internal Combustion Engine Vehicle Powertrain

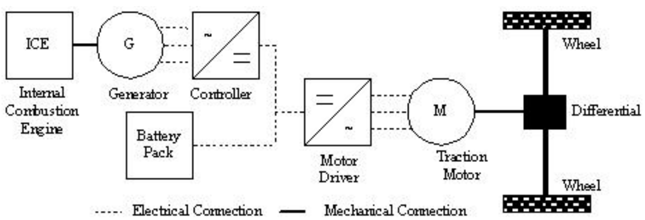

Figure 2. Series Hybrid Electric Vehicle Powertrain

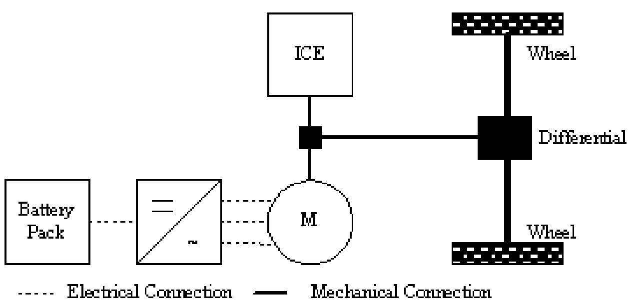

Figure 3. Parallel Hybrid Electric Vehicle Powertrain

These traction systems can include various kinds of elements. In this study, in order to decrease the variance that can be caused by choosing different kinds of traction system elements, gasoline internal combustion engine is selected as ICE, permanent magnet electric motor is selected as electric motor, and nickel metal hydride battery is selected as the battery.

Both series hybrid and parallel hybrid vehicle have the same type of nickel metal hydride batteries. The maximum capacity of one module is 28 Ah, and its nominal voltage is 6 V. The dimensions are 190x102x81 mm and the weight is 3.6 kg. Its nominal energy capacity is 175 Wh and can give 1.6 kW peak power.

The characteristics of subsystems those are used in ICEV, SHEV and PHEV are shown in Table 1. The power and weight values of different traction system elements at each car are given in this table. As you can see from this table, the total traction power of each vehicle is equal to each other. The weight difference between the vehicles is due to the difference between the traction system elements.

Table 1. Powertrain system elements

	ICEV	SHEV	PHEV
P engine (kW)	75	41	41
P generator (kW)	-	75	-
P electric motor(kW)	-	75	34
Number of battery	-	50	25
Battery capacity (Ah)	-	28	28
Curb weight (kg)	592	592	592
ICE (kg)	220	131	131
Electric motor (kg)	-	127	58
Generator (kg)	-	87	-
Battery (kg)	-	180	90
Others (kg)	134	61	125
Load (kg)	136	136	136
Total weight (kg)	1082	1314	1132

The powertrain system elements of each vehicle are the inputs of the simulation program. In order to make comparative evaluation the acceleration and gradeability test simulations have conducted. Another comparison tool is to test the vehicles at different drive cycles and to compare the fuel consumption and total system efficiency. The vehicles are simulated at UDDS(Urban Dynamometer Driving Schedule), HWFET(Highway Fuel Economy Test) and NEDC(New European Driving Cycle).

At each vehicle configuration, same curb weight is selected. Therefore the initial weights of vehicles are same. This shows us, the differences between the weights of vehicles are caused by the different traction systems. The lightest one of these vehicles is ICEV and the heaviest one is SHEV that contains electric motor, battery pack and generator set. In addition, PHEV comprising of electric motor, ICE and a battery pack smaller than series hybrid vehicle is lighter than SHEV and more closer to weight of ICE. The weight comparison of vehicles is shown in Figure 4.

The simulation results showed that the differences between the weights of vehicles caused by different traction systems affect the vehicle performance. The most attractive example is SHEV. At the maximum speed comparison, SHEV is slower than the others, and the PHEV has nearly the same values with ICEV. The maximum speed comparison of vehicles is shown in Figure 5.

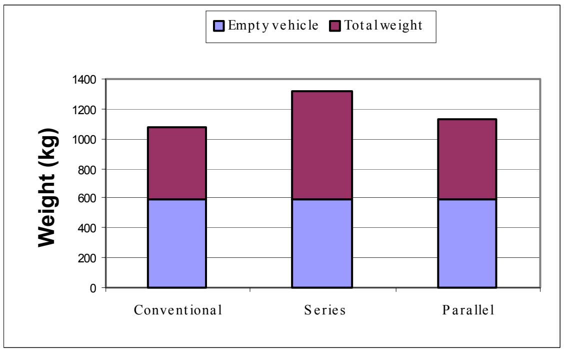

Figure 4. Weight comparison of total vehicle weight

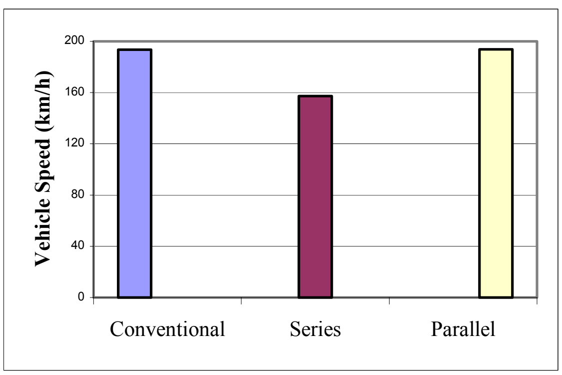

Figure 5. Maximum vehicle speed comparison

When we look at the acceleration times, the disadvantage of SHEV at maximum speed criteria caused by the total weight is not seen. One of the most important factors is the high torque of electric motor at the initial speeds compared with ICE. The total weight of PHEV is closer to ICEV, then the high torque feature of electric motor is supported by lower weight of vehicle, therefore the acceleration is better than the others. The acceleration time graphs are shown in Figure 6.

At the gradeability criteria, same comparison can be done. Due to the weight of SHEV at the same traction power, the gradeability of SHEV is the lowest and PHEV is more capable of gradeability than the both. The gradeability graphs are shown in Figure 7.

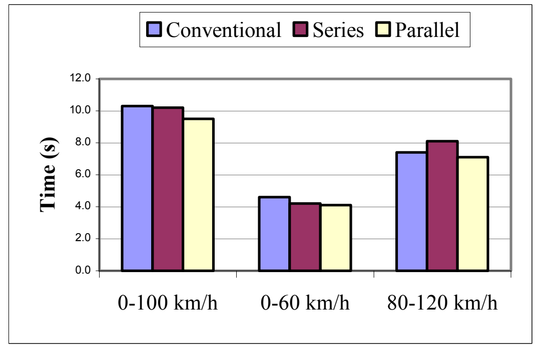

Figure 6. Acceleration time comparison

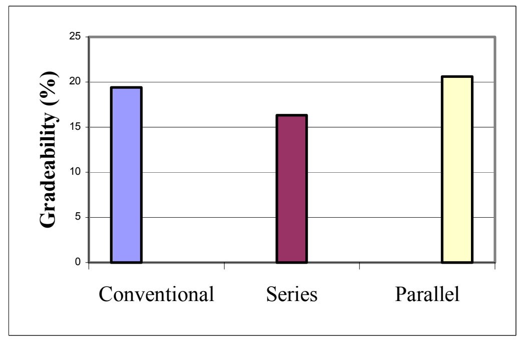

Figure 7. Gradeability comparison

The three vehicles were also simulated at three different drive cycles and the fuel consumptions of the vehicles have been compared. The results are shown in Figure 8. UDDS and NEDC drive cycles are urban drive cycles and similarly same. At these two drive cycles, fuel consumption of ICEV is the highest, fuel consumption of SHEV is attractively lower than ICEV, and fuel consumption of PHEV is lower than SHEV.

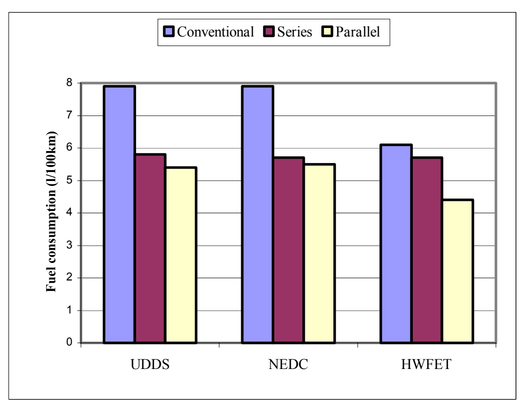

Figure 8. Fuel consumption comparison

One of the most important factors of these results can be understood when we examine UDDS and NEDC drive cycle characteristics. In these urban drive cycles, there are a lot of stops and waiting times (traffic jam, traffic lamps) like we all faced with in daily life. At the ICEV, ICE needs high rpms in order to give the torque to cruise the vehicle. Lots of stops, increase the fuel consumption due to the inefficient low speed characteristics of ICE. In addition, while waiting times, the running of ICE at low speeds is another reason of high fuel consumption. Both SHEV and PHEV have these two advantages compared with ICEV, therefore fuel consumptions are lower. While stop starts the electric motor shows high torque characteristics at low speeds, and while waiting at traffic jam electric motor does not consume energy, so the overall fuel consumption decreases. Regenerative breaking is another plus at urban drive cycles. The electric motor works as a generator and charge the batteries during braking at the stops and downhill driving. SHEV and PHEV use this braking energy that couldn't be used by ICEV. Thus, regenerative energy makes a contribution to overall system efficiency and fuel consumption. When we compare ICEV performances between drive cycles, ICEV has showed a better performance at the HWFET that is a highway drive cycle than the urban drive cycle, due to the decreased disadvantage effect of ICE. The reason is that the vehicle speed is high and not varied. Then, the required power is less than the low speed-high torque characteristic region. Thus, the highway fuel consumption is less than the urban fuel consumption. Although SHEV and PHEV do not have the advantages of start-stops in the urban drive cycle, they both still have better fuel consumption and total system efficiency than the conventional vehicle.

CONCLUSION

In this study, the performance and energy consumption comparison of conventional vehicle, series hybrid vehicle and parallel hybrid vehicle has done. ICEV, SHEV and PHEV are simulated with ADVISOR simulation program at the same test conditions and same drive cycles. SHEV is the heaviest one of those three when their characteristic traction systems are put on the same vehicle. PHEV and ICEV are consequently the others. The vehicle weight affects the vehicle performance directly. Therefore the disadvantage of SHEV at the weight criteria shows itself as low performance at maximum speed and gradeability. PHEV competes with ICEV at these specifications. At the fuel consumption comparison, especially at the urban drive cycles, PHEV and SHEV consequently are better than conventional vehicle. When all these data have been taken into account, PHEV and SHEV are seen as good alternatives for ICEV.

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