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Energy Consumption of the Electric Vehicle and Internal Combustion Engine Vehicle for Different Driving Cases

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주행 상황에 따른 전기차와 내연기관차의 에너지 소비 비교

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ABSTRACT

In this paper, the electric vehicle (EV) and internal combustion engine vehicle (ICEV) are compared for different driving cases. The EV exhibits a lower powertrain efficiency when driven on the aggressive driving cycle than when driven on the moderate cycle. In particular, EV powertrain efficiency is low when the battery state of charge (SOC) is low, but ICEV efficiency increases when the driving cycle changes from the moderate cycle to the aggressive cycle. Based on these results, attempts can be made to increase EV powertrain efficiency. EV charging before the battery power drops to a low charging state can reduce energy consumption by 2.7% for an urban area. Furthermore, ECO driving has a more significant effect on EVs than on ICEVs.

Keywords : Electric Vehicle(전기자동차), Internal Combustion Engine(내연기관), Powertrain(파워트레인), Energy Consumption(에너지소비), Powertrain Efficiency(파워트레인효율)

1. Introduction

An electric vehicle(EV) has an electric motor and a battery as the power source. One-year driving data of a gasoline vehicle showed that a 100mile range limited EV can satisfy 21% of drivers, who never exceed the 150 mile range; therefore, a limited range EV can comprise a certain percentage of the vehicle market if marketed correctly to segments with appropriate driving behavior[1]. But, there were some studies to overcome the limited driving range of EV. The neighborhood EV can offer the enough driving range for the city driving[2-3]. And, the recycle energy such as solar energy is used in the EV to increase the driving range[4-5]. The above researches are about the EV component design for increasing the driving range such as the battery and vehicle mass designs. Thus, the analysis studies of EV were performed to know the component losses and efficiencies of EV[6-7]. However, it needs to know how the above characteristics affect on the driving

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situations of EV.

Thus, in this paper, the energy consumptions of the EV are analyzed for the different driving schedules. And, the above analysis results are compared with internal combustion engine vehicle (ICEV). From the above results, charging strategy and driving velocity are suggested to increase the EV powertrain efficiency.

2. Powertrain Efficiencies for Different Driving Cycles

From the previous study, it was found that the EV and ICEV powertrain efficiencies vary according to the vehicle velocity[7]. Thus, the EV and ICEV powertrain efficiencies will also vary according to the driving cycle. Fig. 1 shows the two different driving cycles used in this study. The FUDS(federal urban driving schedule) represents an urban driving pattern; the US(united states)06 cycle represents driving with a high load, so called aggressive driving cycle. Average velocity and maximum acceleration are shown in table 1. The FUDS is a moderate cycle, and the US06 is an aggressive cycle with 2.5 times higher average velocity and maximum acceleration than those of the FUDS. Using the above cycles, the transmission efficiencies of the EV and ICEV are analyzed. In the previous study, the loss power and efficiency each were analyzed at one point[7]. But, to analyze efficiency over the whole range of a driving cycle, power loss needs to be integrated (mathematically). Thus, the transmission efficiencies are calculated by integrating the power loss over the whole driving cycle range.

Fig. 2 shows the battery, motor and powertrain efficiencies of the EV for the FUDS and US06. The electric motor shows 83.45% efficiency for the FUDS, and increases to 89.14% for the US06. This increase is due to the movement of the electric motor operation points to the high speed region, which

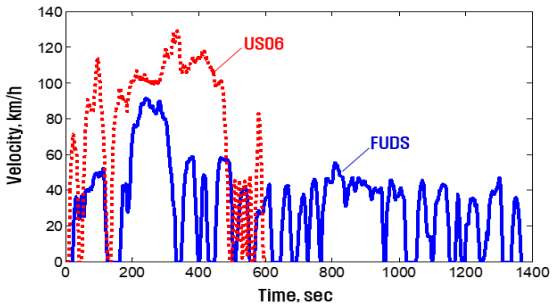
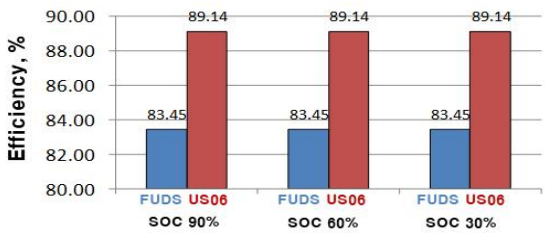


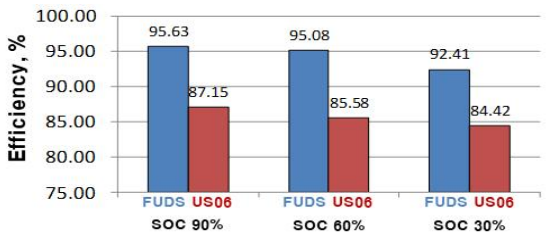
Fig. 1 FUDS and US06

Table 1 Characteristics of the FUDS and US06

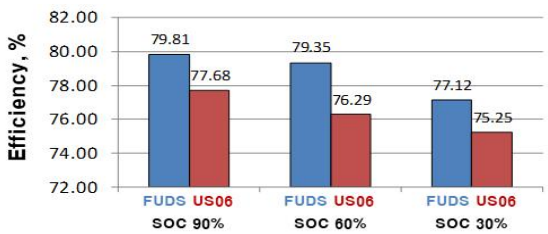
	Average Velocity	Maximum acceleration
FUDS	31.4 km/h	1.5 m/s^2
US06	77.2 km/h	3.8 m/s^2



(a) Electric motor



(b) Battery



(c) Powertrain

Fig. 2 Efficiencies of EV for the FUDS and US06

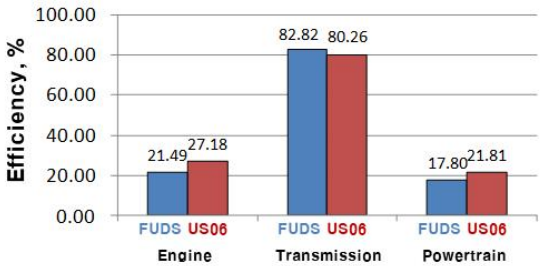


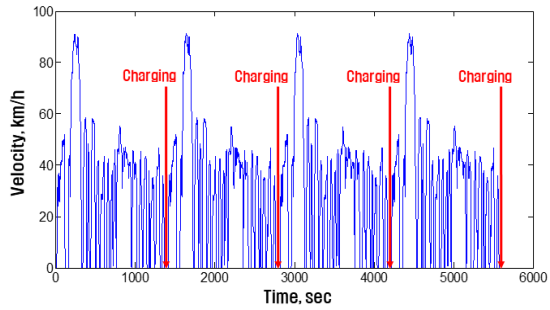
Fig. 3 Efficiencies of ICEV for the FUDS and US06

indicates higher efficiency. The electric motor efficiency does not vary with the battery SOC(state of charge) in both cycles. The battery efficiency ranges 92.41 ~ 95.63% for the FUDS. The battery efficiency is decreased by the battery SOC. For the moderate driving cycle FUDS, the battery efficiency is higher than the electric motor efficiency. However, the battery efficiency decreases by about 10% for the aggressive driving cycle US06, and becomes smaller than the electric motor efficiency. This condition decreases the powertrain efficiency. The powertrain efficiency ranges 77.12 ~ 79.81% for the FUDS, but decreases to 75.25 ~ 77.68% for the US06. This decrease leads to the reduction of the EV driving range when aggressive, high speed and low battery SOC driving is performed.

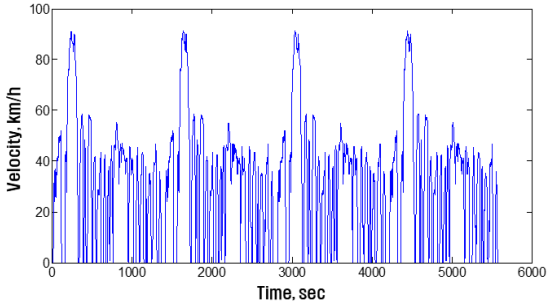
Fig. 3 shows the engine, transmission and powertrain efficiencies of the ICEV for the FUDS and US06. The engine shows 21.49% efficiency for the FUDS, and increases to 27.18% for the US06. This increase is due to the movement of the engine operation points to the high speed region, which provides higher efficiency. The transmission efficiency shows 82.82% for the FUDS, but decreases by a relatively small amount of about 2% for the aggressive driving cycle US06. Thus, the powertrain efficiency shows 17.8% for the FUDS, and increases to 21.81% for the US06. When the driving cycle changes from the moderate cycle FUDS to the aggressive cycle US06, the EV powertrain efficiency decreases, but the ICEV efficiency increases.

3. EV Energy Consumption for Different Charging Strategies

In chapter 2, it is found that the EV powertrain efficiency is decreased when the battery SOC decreases. Thus, if the battery SOC is maintained at a high level by frequent charging, the EV powertrain efficiency can be improved. Recently, many EV charging spots have been established in urban areas. Thus, the EV can be charged, whenever needed, in the downtown area. And, after short range driving, the EV can be charged in the garage. Considering the above situations, two different cases can be considered: EV charging after short range driving (Case 1) and no EV charging after short range driving (Case 2). In this paper, the FUDS is



(a) Case 1: Performing the EV charging after short range driving



(b) Case 2: Do not performing the EV charging after short range driving

Fig. 4 Two different EV charging strategies for the FUDS

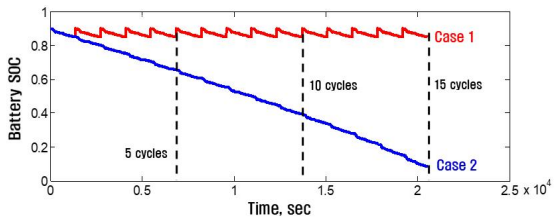


Fig. 5 Two different EV charging strategies for the FUDS

considered to represent urban driving. And, Fig. 4 shows the two different EV charging strategies for the FUDS. The EV charging is performed after a single FUDS in Fig. 4a (Case 1) and no EV charging is performed in Fig. 4b (Case 2).

Fig. 5 shows the battery SOC for case 1 and case 2. The battery SOC of case 1 is sustained between 85.21% and 90% because of the EV charging after a single FUDS cycle. But the battery SOC of case 2 is depleted to lower levels,65.7%, 39.6% and 7.3% after 5, 10, 15 cycles respectively.

Fig. 6 shows the energy consumption of the EV for case 1 and case 2. The EV drives about 60km after 5 cycles of FUDS, and the EV energy consumptions of case 1 and case 2 are 23.73 MJ and 23.79 MJ, respectively. The EV drives about 120km after 10 cycles of FUDS, and the EV energy consumptions of case 1 and case 2 are 47.45 MJ and 47.84 MJ, respectively. The differences of energy consumption between case 1 and case 2 are just 0.26% and 0.81% for FUDS of 5 cycles and 10 cycles, respectively. These small differences are due to similarity in the battery efficiency when the battery SOC is above 40%. But the EV drives about 180km after the 15 cycles of FUDS, and the EV energy consumptions of case 1 and case 2 are 71.18 MJ and 73.10 MJ, respectively. The difference in energy consumption between case 1 and case 2 increases to 2.7%. This is because the battery efficiency decreases when the battery SOC is below 40%. Thus, the EV battery must be charged for smaller energy consumption if the battery SOC is lower than 40%.

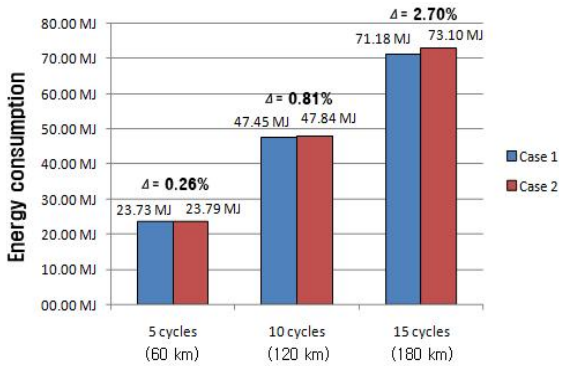


Fig. 6 Energy consumptions of the two different EV charging strategies

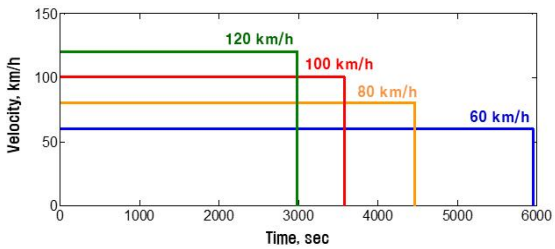


Fig. 7 Driving of 100km distance at different vehicle velocities

4. EV Energy Consumption at Different Vehicle Velocities

On the highway, the EV can be driven at almost constant velocity for a relatively long distance. From the chapter 2, it is found that the EV powertrain efficiency is decreased as the vehicle velocity is increased. Thus, the lower velocity driving (Eco-driving) will result in less energy consumption. Fig. 7 shows the different vehicle velocities for 100km distance driving. The vehicle velocity of 120 km/h yields the fastest driving time of about 3,000 seconds. And, the vehicle velocity of 60 km/h yields a driving time of about 6,000 seconds.

Fig. 8 shows the energy consumption of the EV for different vehicle velocities. When the EV velocity is 120 km/h, the energy consumption is 72.2 MJ. As

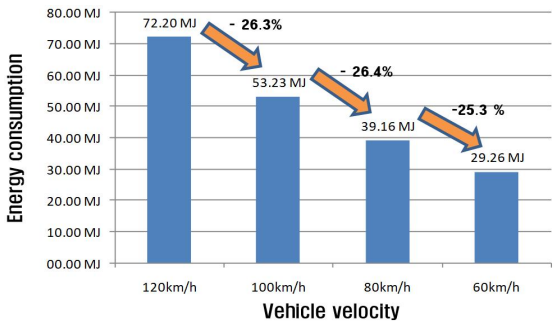


Fig. 8 Energy consumptions of 100km distance driving at different EV velocities

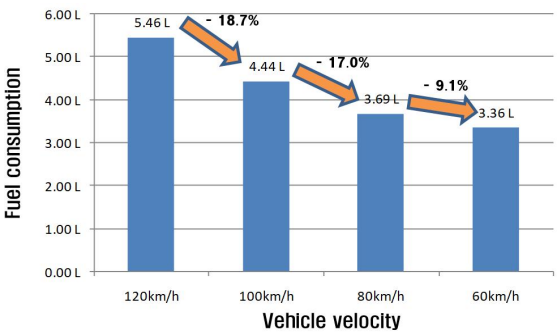


Fig. 9 Fuel consumption of 100km distance driving for different ICEV velocities

the vehicle velocity decreases to the 100 km/h, 80 km/h, and 60 km/h, the energy consumption reduces to 53.23 MJ, 39.16 MJ, and 29.26 MJ respectively. The energy consumption is reduced at a rate of about 26 %, because the EV powertrain efficiency decreases as the vehicle velocity increases. Decreasing the vehicle velocity by half (120 km/h to 60 km/h) can double the driving time, but reduce the energy consumption of the EV by up to 50% (72.2 MJ to 29.26 MJ).

Fig. 9 shows the fuel consumption of the ICEV for different vehicle velocities. When the ICEV velocity is 120 km/h, the fuel consumption is 5.46 liters, and as the ICEV velocity decreases to 100 km/h, 80 km/h, and 60 km/h, the fuel consumption reduces to 4.44 liters, 3.69 liters, and 3.36 liters respectively. The fuel consumption is reduced at a rate of 9.1 ~ 18.7 %, which is smaller than the reduction rate of the EV. When the vehicle velocity decreases from 120 km/h to 60 km/h, the energy consumption of the EV is reduced by 59.5%, but the fuel consumption of the ICEV is reduced by 38.5%. Especially, when the vehicle velocity decreases from 100 km/h to 60 km/h, the energy consumption of the EV is reduced by 45.0%, but that the fuel consumption of the ICEV is reduced by just 24.3%. From the above results, ECO driving has more effect on the EV than on the ICEV.

5. Conclusion

In this paper, the electric vehicle(EV) and the internal combustion engine vehicle(ICEV) were compared for the different driving cases. The EV showed a lower EV powertrain efficiency when the EV was driven on the aggressive driving cycle than when it was driven on the moderate cycle. Especially, the EV powertrain efficiency was low when the battery SOC was low. Thus, the driving range of the EV can be expected to reduce for the aggressive, high speed and low battery SOC driving. However, the ICEV showed different characteristics from those of the EV. The ICEV efficiency increased as the driving cycle changed from the moderate cycle to the aggressive cycle. From the above results, attempts can be made to increase the EV powertrain efficiency. EV charging before the battery power drops to a low charging state can reduce energy consumption, by 2.7% for an urban area. Also, it was found that ECO driving had more effect on the EV than on the ICEV. When the vehicle velocity decreased from the 120 km/h to 60 km/h, the energy consumption of EV was reduced by 59.5%, but the fuel consumption of the ICEV was reduced 38.5%. Especially, when the vehicle velocity decreased from 100 km/h to 60 km/h, the energy consumption of the EV was reduced 45.0%, but the fuel consumption of ICEV was

reduced by just 24.3%. Thus, the limited driving range and less driving power were helpful to the EV, because such conditions increased the EV powertrain efficiency.

Acknowledgement

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