International Journal of Energy Applications and Technologies
Available online at
http://dergipark.gov.tr/ijeat/issue/30402
Research Article
Vol. 4
Issue 2
pp. 64-72
Year
2017

IMPACT OF VEHICLE HYBRIDIZATION ON FUEL CONSUMPTION ECONOMY

Javad Rezaei

Department of Mechanical Engineering, Iran University of Science and Technology, Iran

Abstract

Air pollution, limited number of known petroleum resources and increasing of greenhouse gases have led the governments and researchers to have more investigation on Hybrid Electric Vehicles. Considering technical availability and manufacturing facilities with regarding to the final vehicle price, hybridization of conventional vehicles could be a better choice than designing and manufacturing a new hybrid electric car.

Parallel-Series hybrid electric vehicles (power-split) which is used in this study have low pollution and fuel consumption compared to other hybrid structures and could be an appropriate choice for hybridization. In addition, electric assist control strategy (EACS) is used as an efficient strategy in this study since this method could decrease fuel consumption and engine emission significantly for conventional vehicles and has been used in most of successful commercial hybrid vehicles recently.

Gt-Power software is used for modelling the Peugeot 206 vehicle platform and the proposed control strategy in this study. For the testing and validation, standard international cycles for urban and highway (FTP-75 and HFET) are used for both conventional and hybrid vehicle and results showed significant reduction in fuel economy for both cycles, in particular for urban cycle, this control strategy had the best efficiency and fuel consumption reduced up to 27.6%.

Key words: *Hybrid Electric Vehicle, EACS, Fuel consumption reduction*

Paper submitted: May 03, 2017

Paper accepted: August 01, 2017

Corresponding author, Javad_Rezaei@alumni.iust.ac.ir

1. Introduction

Nowadays, the importance of air pollution and limited fossil fuel resources and high prices of these fuels has become one of the government's main concerns. Normal vehicles using internal combustion engines are the most important air pollutants, including major consumers of fossil fuels [1]. Thus, the governments and different companies have been looking for better alternatives for current vehicles in recent years. In order to achieve this objective, different solutions have been provided by research centers and automotive industries. Hybrid vehicle is one type of vehicles presented as a solution for the future transport as an efficient vehicle [2].

One important issue in hybrid vehicles is accurate management and control of power supply sources using vehicle control strategy. Hybrid vehicle control strategies are complicated and researchers used different methods for it and different methods proposed in different studies [3-6].

Hybridization of the vehicles in some countries started with changing internal combustion engines which were using natural gas. But producing these vehicles need massive investment for construction of gas stations. Thus, according to lower consumption in the urban cycle, hybrid electric vehicles look more suitable than hybrid vehicles running on natural gas. According to features and structures of car factories in every country, producing hybrid vehicle by changing the current vehicle is a suitable alternative for hybridization. For designing a new hybrid vehicle, internal combustion engine should be downsized and redesigned in addition to some other vehicle parameters which should be noticed for other parts of vehicle which finally increase the manufacturing cost of vehicle significantly. Using conventional vehicles in market for hybridization will be more efficient in terms of cost, engineering efforts, applicability and convenience. There are some studies for hybridization using fuel cell and fuel consumption optimization [7-9], but there is gap in literature for hybridization of a passenger vehicle using parallel series structure and smart control strategy for fuel consumption reduction while being cost effective. Using this method will decrease fuel consumption and consequently vehicle emission for different driving cycles.

In the study, first different structures of hybrid vehicles are demonstrated. Then, control strategy used has been explained. In next section, modelling the Peugeot 206 vehicle in the GT-POWER software is described and finally the performance test results on urban and road cycle will be displayed and amount of improved fuel consumption will be calculated for both cycles and results discussed in conclusion.

2. Structures of Hybrid Vehicle

Depending on how we use the power supply sources in hybrid vehicles, the structure of these vehicles is divided into different categories including series, parallel and parallel-series [10].

2.1. Series hybrid vehicle

The simplest structure for hybrid vehicle is series structure. That is the reason why this structure has been considered and examined for a long time, especially in heavy vehicles. To explain the series hybrid vehicle, consider an electric car which the electric motor is responsible for supplying the driving for the wheels and use series with a combustion engine in addition to generator to charge the battery with a power output. It is clear that because of charging, these vehicles have more board comparing to electrical vehicles. The scheme structure of power systems in series hybrid vehicle in Fig. 1 is shown [11].

2.2. Parallel Hybrid Vehicle

Parallel hybrid vehicle uses its both energy converters to supply the driving force of the wheel. The difference between these structures with series is that each of the energy converters (combustion engine and electric motor) can transfer their required driving force to wheels through power transfer system alone or simultaneously - parallel to each other. As we see in Fig. 2, in this situation the electric motor can act as a generator and charge the battery. Each of the energy converters in series structures can act as main power and the other is used as an auxiliary unit. But the combustion engine is usually used as driving force and electric motor is used as auxiliary unit. Thus, combustion engines used in parallel vehicles are usually larger than the ones in series vehicles. But electric motors in parallel structures are smaller than the ones in series, meaning the series hybrid vehicles need smaller battery to reduce cost and weight of the vehicle significantly [12].

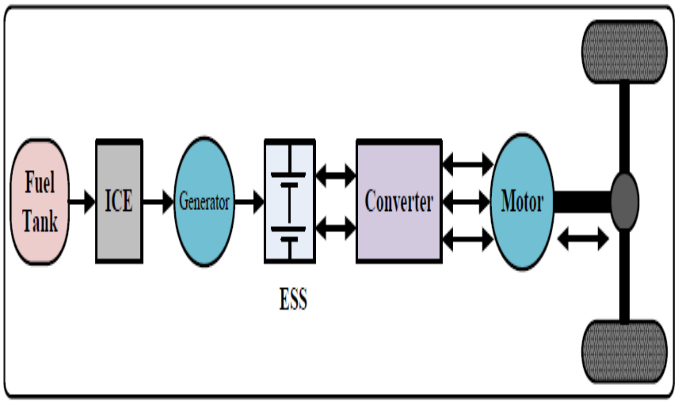

Fig. 1. The structure of series hybrid vehicles.

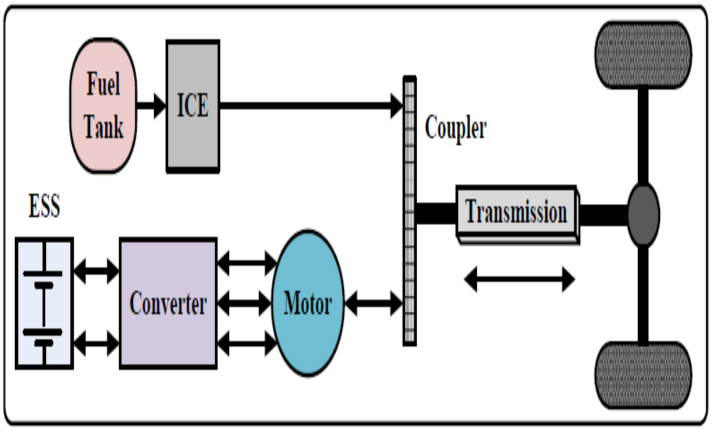

Fig. 2. The structure of parallel hybrid vehicles.

2.3. Parallel-Series Hybrid Vehicle

This arrangement is an attempt to combine the advantages of series and parallel arrangements. This structure was introduced by Japanese for the first time and its efficiency was proved by presenting Toyota Prius.

International Journal of Energy Applications and Technologies, Year 2017, Vol. 4, No. 2, pp. 64-72

There are two modes for this compound: switching configuration and split configuration. When the clutch is not engaged in switching arrangement the system acts as series which means only electric motors can give power to the wheels [13].

Such an energy flow is exactly identical to the one in series arrangements. Combustion engine will also supply power by engaging the clutch. The system acts as a combination of series and parallel arrangements.

A power split device (PSD) is needed to divide the output power of the combination engine in to series and parallel routs. The dissipated energy during break is recovered by connecting to generator for charging the battery which is called regenerative breaking is one of the reasons why this structure has high efficiency.

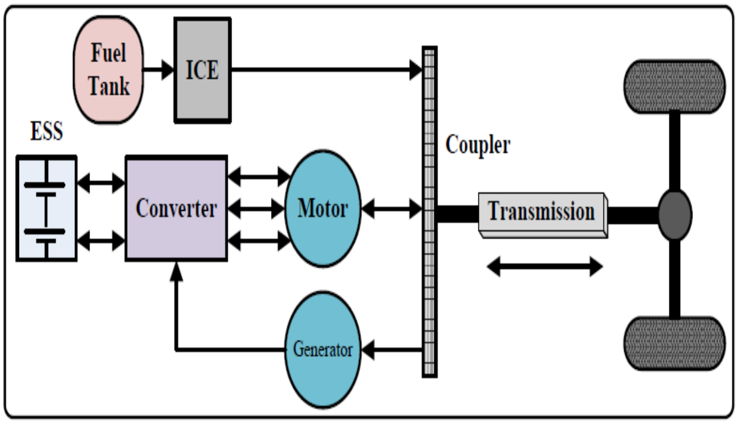

Fig. 3. The structure of parallel-series hybrid vehicle.

3. Vehicle Control Strategy

Most of the successful commercial hybrid vehicles which are used in the world and far more affordable in term of fuel consumption use electric assist control strategy (EACS) as an efficient method [2]. The electric motor is used as additional force when is needed.

The main purpose is to approach the internal combustion engine performance, efficiency, greenhouse gas emissions to the optimum fuel economy at a certain speed.

The variation between the force required by the driver and the force generated by the internal combustion engine in optimum condition will be produced by electro motor or compensated in case the charge is excess.

In this control strategy we try to optimum the combustion engine operating points at any moment. To achieve this purpose, according to the combustion engine's speed at a special moment, the optimum torque in that speed in regard to performance criteria is described and calculated. Then, according to the requested torque and the charge level of batteries this torque is corrected and the output torque of the combustion engine and the requested torque for electric motor are supplied. Optimal operating points of the combustion engine are determined according to the parameters used in engine and instantaneous engine speed, to minimize fuel consumption.

On the other hand, the control strategy ought to cause the vehicle to pursue the steering. This means the distribution of torque between the combustion engine and electric motor must be done in a way the driver torque demand (Gas and brake pedals) is done very well. Other issue is that minimizing the fuel consumption in a vehicle shouldn't sacrifice dynamic performance of the vehicle (such as acceleration and climbing).

Thus, some performance standards for different vehicles are described. In this study, performance standards of PNGV are used as design constraints in the optimization process. Other important issue we should consider is the situation of batteries charge which must remain in a reasonable range and in this strategy, it has been resolved [15].

To better examine the different situation of hybrid vehicle performance, engine maps can be used. So by using it simultaneously with the electric map all operating points can be viewed. To further describe the control strategy, divide motor plan and electromotor in to five separate points and investigate car working conditions for each condition. As we see in Fig. 4, working points of the internal combustion engine can be divided in to optimal operating points, maximum operating points and non-optimal operating points. The electric motor can generate a fixed torque with a special speed from this point on; the output torque is decreased by increasing the speed.

If the optimal operating point of the hybrid vehicle locates area 1, in regard to high amount of demanded torque, the internal combustion engine and electro motor must worth simultaneously to supply the demanded torque for the vehicle. (In case the charge of the battery is suitable)

If the optimal operating point of the hybrid vehicle locates area 2, since the general approach of this strategy is working the internal combustion engine in optimum range as far as possible, thus engine works in optimum state in this condition and additional needed torque is supplied by electro motor. However, it happens when the battery charge level is appropriate and it can supply the energy needed for electro motor. Otherwise engine is forced to work in non-optimal state.

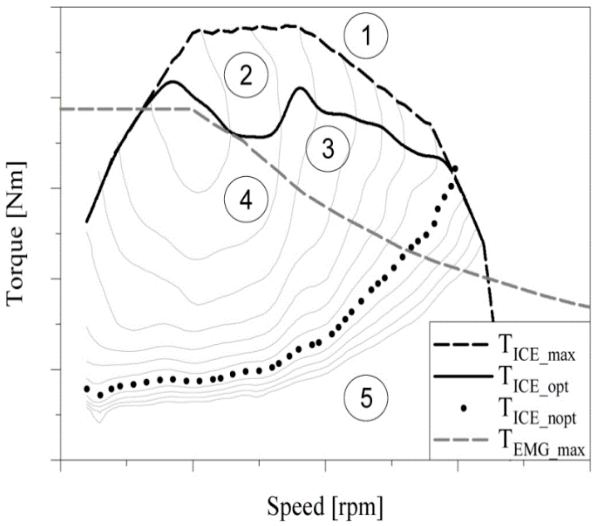

Fig. 4. Internal combustion engine and electro motor schematic map.

If the operating point of the vehicle locates area 3, like before since the general approach of this strategy is working in optimum area, the decision made by controller is the internal combustion engine works in optimum area and increases the charge level through additional torque made by generator.

If the operating point of the vehicle locates area 4, since the point is in electro motor performance area the controller decides to activate electro motor and continues until the battery charge level decreases. Controller turns the internal combustion engine on while it forces the electro motor to be on for the needed torque. So it works in optimum point and uses the whole torque for charging the battery and the charge level reaches the ideal one again, then it turns off.

If the operating point of the vehicle locates area 5, like before the needed torque for the vehicle is supplied by electro motor. Because it is not a suitable area to turn on the combustion engine since in this point the efficiency of the vehicle is low and the fuel consumption rises. Thus, the electro motor supplies the needed torque for the vehicle as far as battery charge level are appropriate. By reducing the charger level, the combustion engine is switched on and by working in its optimum area through generator the battery charge level reaches its optimum level.

4. Vehicle Modelling

GT-POWER is a useful and developed software in designing and analysing internal combustion engines, vehicles and hydro-thermal systems which is designed by Gamma Technologies and it is the most important commercial software in engine simulation. The software initially produced and developed by Professor John B. Heywood and has grown in the past decade.

In this study, the Peugeot 206 vehicle type 5 has been modelled by the software and tested on cycles and the level of fuel consumption has been calculated. Then hybrid structure which is obtained by adding electro motor, generator and battery has been modelled (Fig. 5). The level of fuel consumption is calculated on cycles and compared to previous state finally the improved fuel economy is achieved. In this study, we use 40 kW electro motor and 35 kW generator and 30 nickel-metal hydride batteries (Ni-MH) as electrical energy storage to hybrid-up the conventional 206 vehicle. General specifications of the vehicle used in this study in table 1 are shown [14].

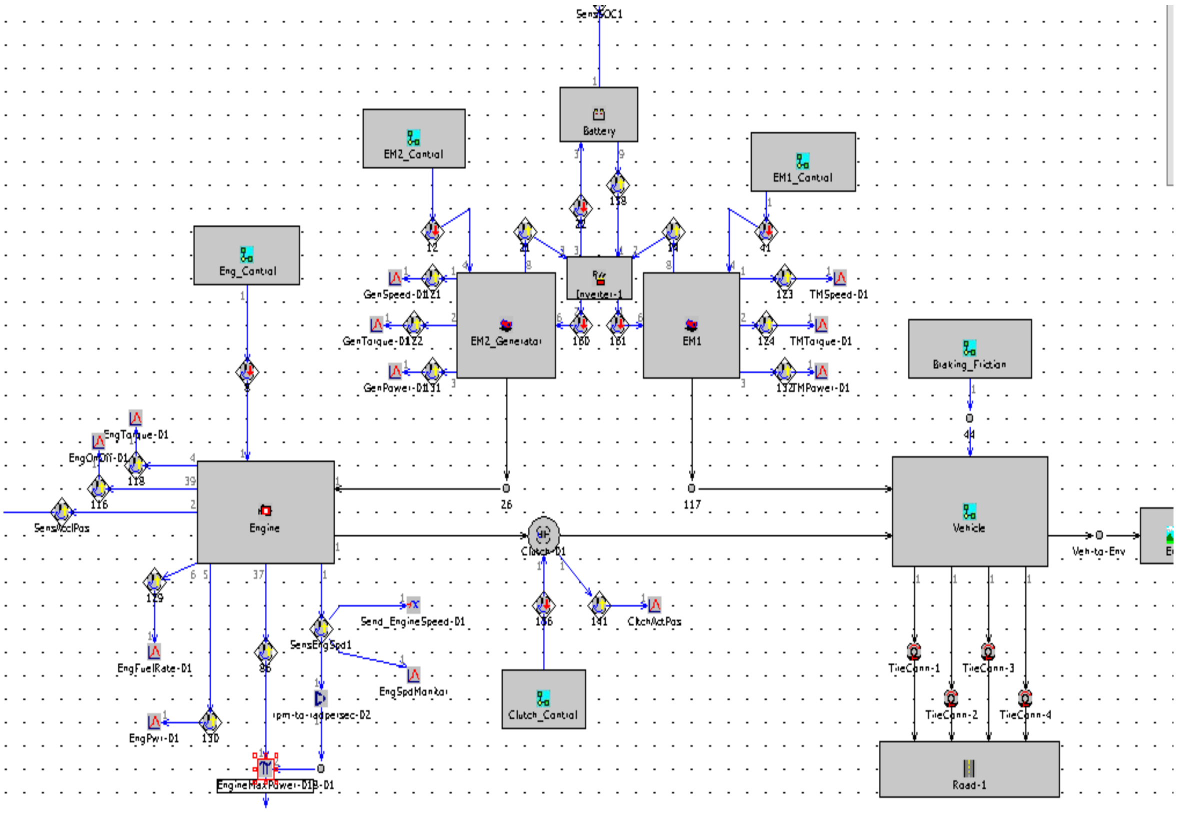

Fig. 5. The modelled vehicle in GT-Power software.

5. Driving Cycles

Driving cycles are speed versus time curves which are used for special type of vehicle in a moving environment with specific characteristics, show patterns for driving for that vehicle in specific situation. A moving cycle indicates traffic, driving culture, vehicle dynamics and traffic conditions in a city.

In real standard cycles we can point to FTP-75 (Fig. 6). This cycle has been generated in the U.S urban cycles and obtained based on experimental measurements. HWFET cycle is also one of the standard cycles for examining vehicles in road paths (Fig. 7).

Table 1. General specification of Peugeot 206 type 5

Characteristics	Amount
Type of the engine	TU5
Engine size	1587cc
Engine power	110 hp @ 5800 rpm
Maximum torque	142Nm @ 4000 rpm
Type of the fuel	octane 95 gasoline
Combustion system	Spark ignition
Number of valves	16
Standard limit emissions	Euro III
Maximum speed (km/h)	198
Average consumption in highway	5.1 Liter
Average consumption in urban	8.6 Liter
The average combined consumption	6.4 Liter
The approximate weight of the vehicle	1054 kg

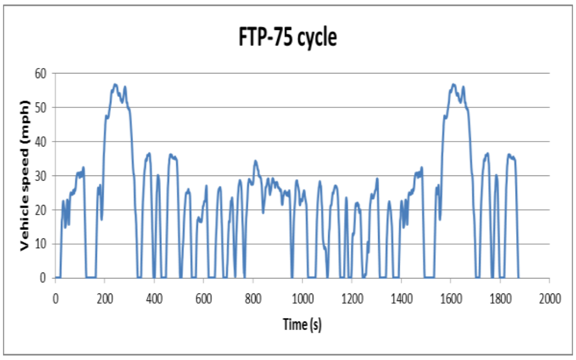

Fig. 6. FTP-75 urban driving cycle.

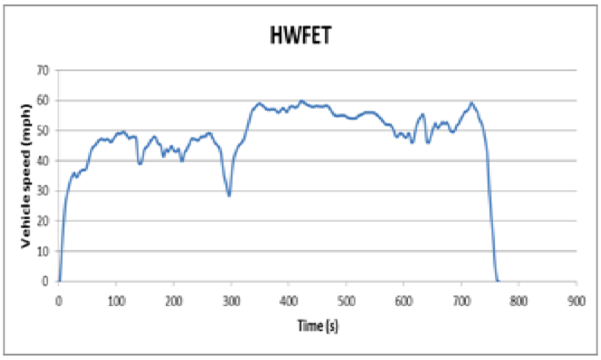

Fig. 7. HWFET road driving cycle.

6. Simulation Results

In this chapter the simulation results on vehicles in urban and road cycles will be discussed. To evaluate the results of the hybrid vehicle model, the results of non-hybrid model on two cycles is calculated and compared with the hybrid situation.

6.1. Investigation of Simulated Vehicle in Urban Cycle

Urban cycles are very important in investigating different vehicles. It can be mentioned that the most important part of the using vehicles are in cities and urban cycles. These types of cycles can be good examinations for investigating vehicle fuel consumption due to the large amount of stopping and acceleration as well as low operating speed due to urban conditions such as traffic and other obstacles.

Fig. 8 shows combustion engine braking power at some points that has been switched on and helped moving the car. As we see in the figure, the combustion engine was switched off in many parts of the cycle because of low speed and the electro motor has supplied the needed torque and the vehicle performed as a series hybrid vehicle (Fig. 9). The points that combustion engine producing constant power is for battery charging, so when battery state of charge goes below the specified level, combustion engine turns on just for charging the battery using generator and after charging the battery will become off again. Combustion engine works in optimum point while charging the battery. The points which the electro motor power is negative relates to the time it acts as a generator and converted power produced by brake recovery to electric energy which it can be seen that using this method has significant impact on recovering energy and increasing vehicle efficiency.

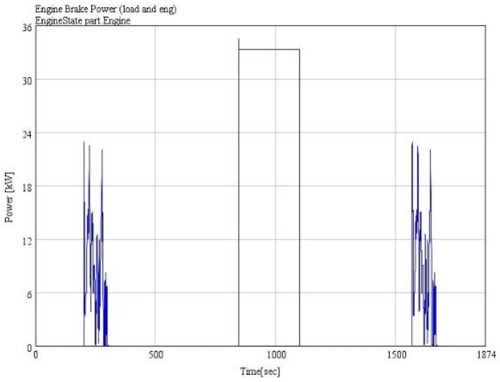

Fig.8. Combustion engine power in urban cycle.

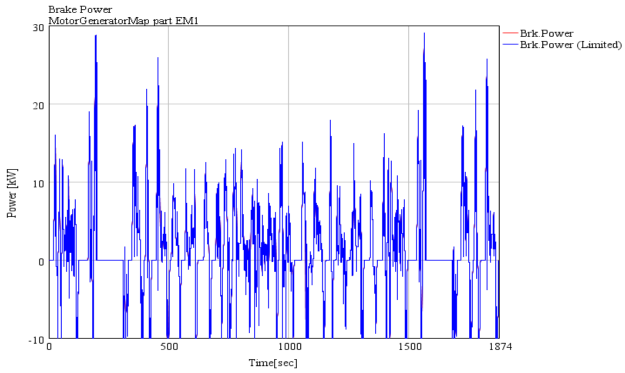

Fig. 9. Electro motor brake power in urban cycle.

6.2. Investigation of Simulated Vehicles in Road Cycle

Road cycle is also important in investigation of hybrid vehicle performance when facing different conditions of driving and examine vehicle performance for high speeds and torques.

Fig. 10 and 11 respectively show brake power of combustion engine and electric motor. As it's shown in the figure the role of combustion engine in road cycle is mainly important since the vehicle needs higher torque. So in comparison with urban cycle, combustion engine is on in most part of the road cycle and electro motor acts as an additional power when high torque is requested.

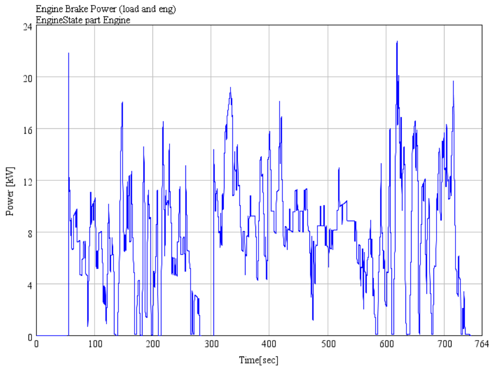

Fig.10. Combustion engine power in road cycle.

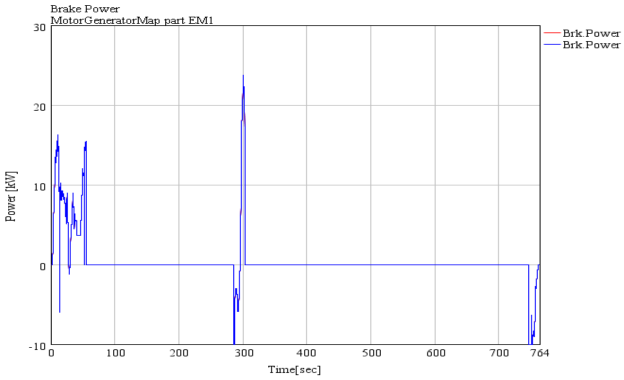

Fig. 11. Electro motor brake power in road cycle.

7. Conclusion

In this study, a conventional vehicle used for hybridization due to the hybrid vehicles advantages. Gt-Power software is used for vehicle and its control strategy simulation. In previous parts, the hybrid vehicle performance was investigated for both urban and highway cycles. These cycles were also examined by conventional vehicle (non-hybrid) and their fuel consumptions are calculated comparing to hybrid. The following table shows results of different cycles for hybrid and typical vehicles.

Table 2. Comparing the results for different cycles and non-hybrid and hybrid vehicle.

	Conventional vehicle fuel consumption (liter)	Hybrid vehicle fuel consumption (liter)	Improvements in fuel consumption percentage
FTP-75 Urban cycle	1.385	1.003	27.6%
HFET Highway cycle	0.833	0.720	13.5%

As it is shown in table 2, the level of improvement in fuel consumption for urban cycle is higher and hybridization made 27.6% fuel economy improvement in urban cycle while for highway cycle is just 13.5% and this is related to the performance of electro motor in urban cycle which is higher and also the performance of combustion engine is lower. So, if the combustion engine switches on, it works in optimum point. But in road cycle the reverse is true due to the high speed and high torque and the vehicle performance is close to typical vehicle (non-hybrid). Also with considering the combination of urban and highway driving with half portion, about 20.5% of fuel consumption reduction can be achieved which also leads to significant impact on engine emission reduction. It can be seen that with hybridization of conventional vehicles, significant amount of fuel consumption will be reduced and in this method, the evaluated price to change a conventional vehicle to hybrid is almost low in compare with the vehicle price.

References

[1] Paganelli, G., Ercole, G., Brahma, A. and Guezennec, Y., 2008, "General supervisory control policy for the energy optimization of charge-sustaining hybrid electric vehicles", *JSAE Review*, 22, 511-518.

[2] Ehsani, M., Gao, Y., Gay, S. and Emadi, A., "Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory and Design", *FL: CRC Press*.

[3] Lin, C., Filipi, Z., Wang, Y., Louca, L., Peng, H., Assanis, D. and Stein, J., 2001, "integrated, feed-forward hybrid electric vehicle simulation in SIMULINK and its use for power management studies", *SAE Paper*, 2001(01), 1334.

[4] Lin, C., Peng, H., Grizzle, J. and Kang, J., 2011, "Power management strategy for a parallel hybrid electric truck", *IEEE Transactions on Control Systems Technology*, 11, 839-849.

[5] Lin, C., Peng, H., Grizzle, J., Liu, J. and Busdiecker, M., 2003, "Control system development of an advanced-technology medium-duty hybrid electric truck", *SAE Paper*, 2003(01), 3369.

[6] Schouten, N., Salman, M. and Kheir, N., 2009, "Fuzzy logic control for parallel hybrid vehicles", *IEEE Transactions on Control Systems Technology*, 10, 460-468.

[7] Ayad, M., Becherif, M. and Henni, A., 2015, "Vehicle hybridization with fuel cell, supercapacitors and batteries by sliding mode control", *Renewable Energy*, 36, 2627-2634.

[8] Liao, G., Weber, T. and Pfaff, D., 2013, "Modelling and analysis of powertrain hybridization on all-wheel-drive sport utility vehicles", *Part D: Journal of Automobile Engineering*, 218, 1125-1134.

[9] Thounthong, P., Chunkag, V., Sethakul, P., Davat, B. and Hinaje, M., 2009, "Comparative study of fuel-cell vehicle hybridization with battery or supercapacitor storage device", *IEEE Transactions on Vehicular Technology*, 58, 3892 – 3904.

[10] Mierlo, V., 2000, "Views on hybrid drive train power management", *Proc. of the 17th International Electric Vehicle Symposiom*.

[11] Kolmanovsky, I., Nieuwstadt, M. and Sun, J., 2017, "Optimization of complex powertrain systems for fuel economy and emissions", presented at *IEEE International Conference on Control Applications*, Hawaii.

[12] Won, J., Langari, R. and Ehsani, M., 2009, "An energy management and charge sustaining strategy for a parallel hybrid vehicle with CVT", *IEEE Transaction on Control*, 13, 313-320.

[13] Baumann, B., Washington, G., Glenn, B. and Rizzoni, G., 2008, "Mechatronic design and control of hybrid electric vehicles", *IEEE/ASME Transactions on Mechatronics*, 5, 58-72.

[14] https://www.auto-data.net/en/?f=showSubModel&modeli_id=567

[15] Desai, C., 2010, "Design and optimization of hybrid electric vehicle drivetrain and control strategy parameters using evolutionary algorithms", Msc. thesis, Concordia University.