A Strategic Mild Hybrid Technology for Reducing Pollution and Optimization of Fuel Sources

H. Biglarian[1], S. M. Keshavarz[2], M. Sh. Mazidi[1,*,] F. Najafi.[1]

1. Faculty of Optimization and Development of Energy Technologies Division, Research Institute of Petroleum Industry (RIPI), Tehran, Iran 2. MS Graduated, School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran

*mazidim@ripi.ir

Abstract

Many studies have been done on hybrid vehicles in the past few years. The full hybrid vehicles need a large number of batteries creating up to 300 (V) to meet the required voltage of electric motor. The size and weight of the batteries cause some problems. This research investigates the mild hybrid vehicle. This vehicle includes a small electric motor and a high power internal combustion engine. In most cases the car's driving force is created by an internal combustion part. A small electric motor, which can operate as engine starter, generator and traction motor, is located between the engine and an automatically shifted multi-gear transmission (gearbox). The clutch is used to disconnect the gearbox from the engine when needed such as during gear shifting and low vehicle speed. The power rating of the electric motor may be in the range of about 15% of the IC engine power rating. The electric motor can be smoothly controlled to operate at any speed and torque, thus, isolation between the electric motor and transmission is not necessary. The present study evaluates the properties of the mild hybrid vehicle, its structure and performance and proposes an energy control model for its optimum operation.

***Keywords**: mild hybrid electric vehicle, environmental pollution reduction, fuel consumption reduction, energy losses, control strategies*

1. Introduction

One of the main concerns in this century is air pollution and the serious damages to the environment. Another subject which rises attention to the need for change in common technologies in vehicle technology is the optimization of fuel consumption in internal combustion engines and energy saving. Scientists have always tried to create vehicles with improved performance, lower fuel consumption and less pollution. Various automobile manufacture companies have carried out vast amounts of research on the increase of heat efficiency and fuel consumption optimization of internal combustion engines. In this respect, many attempts have been done to increase the quality of consumed fuels in vehicles or to change the type of engine from gasoline type to other types in vehicles.

After a lot of research, scientists have come to a conclusion that the best possible vehicle to meet their desires completely is in fact a hybrid vehicle. A hybrid vehicle is a vehicle which incorporates two or more energy producing sources and energy convertors for power production. These two sources of energy can be of any kind, but the most common is a combination of battery and fossil fuel. Common convertors which are being used today in hybrid vehicles are electric and internal combustion engines.

In this way, one can design vehicles with negligible pollution and an appropriate acceleration power. On the other hand, two types of energy source exist in hybrid vehicles, and the simultaneous control of both sources can be tricky. The control and function of these two sources determine some parameters such as fuel consumption, produced pollution and battery life of vehicles. The commercial supply of hybrid electric vehicles is a short term or medium term plan. Experts in this field believe that hybrid vehicles can be considered as a simple solution for fuel consumption optimization and air pollution reduction. In the following paper, after reviewing the technology of hybrid vehicles, a new concept of hybrid vehicles entitled "mild hybrid vehicles" will be presented along with an introduction to its structure and features.

Control strategy is a controlling program which is set beforehand in the controlling driving force system. The selection of one of the operational states mentioned above, depend on the required power, the state of charge of batteries and the speed of vehicle. The controller of the driving force system, receives real time signals from the driver and the accessory parts, and then issues operational orders to each part according to a control program which is adjusted in advance. Gao and Ehsani [1] presented a method for battery charge and discharge. The system presented maintains the overall efficiency of vehicle in an optimum level in any working condition with the use of an appropriate control strategy in a way that the electric engine begins to work as compensator in conditions where the power of the internal combustion engine is not sufficient and also, in conditions where the power of the internal combustion engine is more than the necessary amount, the extra energy is stored in the batteries.

A mild hybrid vehicle does not have major differences with full hybrid vehicles in terms of hardware but, it can be different in terms of control algorithm. In other words, mild hybrid vehicle is in fact a hybrid vehicle with a lower degree of hybridization (about 15%). In this vehicle, the scale size of the electric driving force component is smaller in respect to a full hybrid vehicle due to the fact that, the production of propulsion energy is mainly upon the internal combustion engine [2].

In mild hybrid vehicle, due to the low level of electric engine power, the DC voltage level of the feed engine declines and so, lower number of batteries are needed, thus, the weight and volume of batteries and the overall weight of vehicle drops significantly in comparison to a full hybrid vehicle. The voltage level of the electric engine feed in mild hybrid vehicles is considered about 42 (V). This level of voltage has been chosen based on the presence of consumers and electric charges in a new hybrid vehicle [3]. It should be mentioned that, a 12 (V) battery can also be used for supplying energy to conventional charges in a vehicle. Super capacitors are also used as another component for storing energy to supply instant currents and to set up electric engine [4].

Table 1. Features of the vehicles used in simulation

		Conventional	Mild Hybrid
Vehicle Configuration	Type	VHE_SMCAR	VHE_SMCAR
	Mass (kg)	592	592
	Rolling Resistance Coefficient	0.0054	0.0054
	Aerodynamic Drag	0.25	0.25
	Project Area (m^2)	1.9	1.9
	Wheel Radius (m)	0.282	0.282
Combustion Engine	Type	Geo Metro 41 kW 1.0 Liter	Geo Metro 41 kW 1.0 Liter
	Mass (kg)	131	131
	Thermal Efficiency (%)	34	34
Electrical Motor	Type	----------------	8 kW, AC
	Mass (kg)	--	14
	Electrical Efficiency (%)	--	93
Gear box	Type	5-speed manual transmission	5-speed manual transmission
	Mass (kg)	114	114
	Mechanical Efficiency (%)	95	95
Battery	Type	--	Nickel-Metal Hybrid
	Number	--	9
	Feeding Voltage (V)	--	122
	Mass (kg)	--	104
Total Mass (kg)		984	1100

For the selection of electric traction engine, brushless DC engine with no is taken into consideration due to its superb features. Some of the outstanding features of these engines can be referred to as low sound pollution, high efficiency, reduced number of requirements for motion, low maintenance and longer life time, ease of control, simple structure and lower weight [5].

Overall, it can be stated that in the design of electric driving force system, selection of battery with high power density and low energy, selection of engine and designing of controller with appropriate energy are some of the most important subjects. The design and manufacture of couplings, gear box and a system of force transmission have greater importance in the mechanical driving force section and in fact the art of coordinating two mechanical and electric driving systems are other essential factors in the design and manufacture of mild hybrid vehicles.

2. Simulation

In order to investigate the various parts of a mild hybrid vehicle with parallel structure, a simulation of different states of a mild hybrid vehicle from the main sample to the parallel mild hybrid vehicle will be conducted in the ADVISOR software.

The common features of the two vehicles used for simulation; conventional and parallel mild hybrid, are given in Table 1.

First of all, the auxiliary control strategy parameters are optimized. Since the main goal of designing a mild hybrid vehicle is to reduce fuel consumption and pollution in cities, it is obvious that the best cycle for optimization of control strategy parameters is a city cycle. Therefore, the driving cycle of UDDS is designed for this purpose. Additionally, other driving cycles mentioned such as FTP, HWFET and NEDC are used for comparing results of simulation using the ADVISOR software.

These cycles have been produced through standard tests from driving cycles of cities and motorways in Europe and US. These four driving cycles which are actually the diagrams demonstrating the speed of vehicle verses time are presented in Figures 1 to 4 and the technical features in these cycles have been given in Table 2.

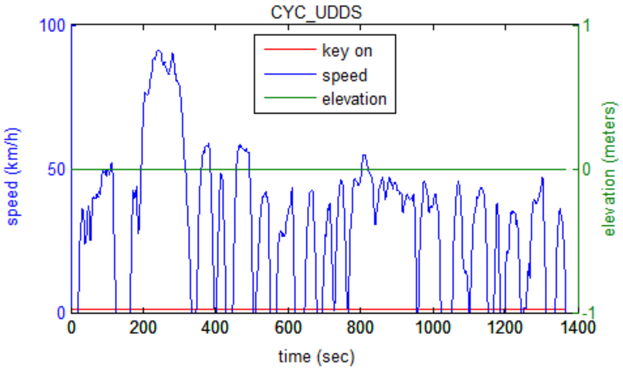

Fig1. Driving cycles of UDDS used for simulation

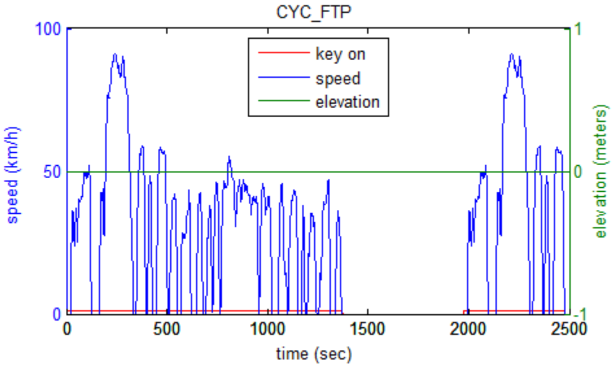

Fig2. Driving cycles of FTP used for simulation

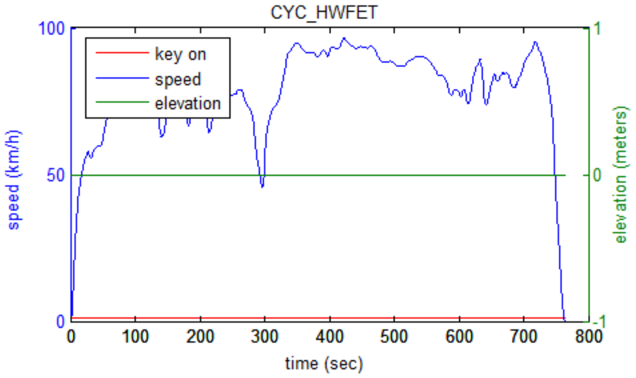

Fig3. Driving cycles of HWFET used for simulation

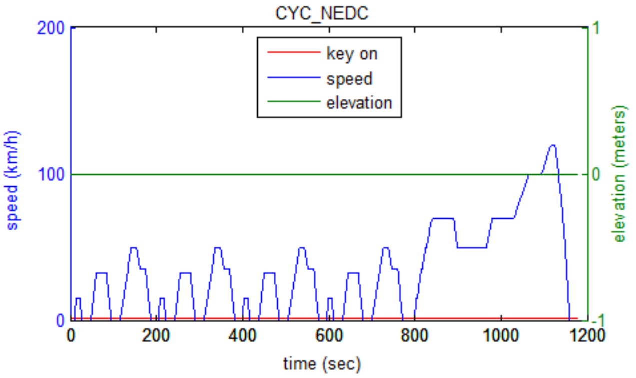

Fig4. Driving cycles of NEDC used for simulation

Table2. The technical features in driving cycles used for simulation

	UDDS	FTP	HWFET	NEDC
Time duration (s)	1369	2477	765	1184
Distance (km)	11.99	17.77	16.51	10.93
Mean speed (km/h)	31.51	25.82	77.58	33.21
Max. speed (km/h)	91.25	91.25	96.4	120
Max. acceleration (m/s^2)	1.48	1.48	1.43	1.06
Max. deceleration (m/s^2)	- 1.84	- 1.84	- 1.84	- 1.39
Mean acceleration (m/s^2)	0.5	0.51	0.19	0.54
Mean deceleration (m/s^2)	- 0.58	- 0.58	- 0.22	- 0.79
Total stops' time (s)	259	361	6	298
No. of stops	17	22	1	13

Table3. Results of simulation for a conventional vehicle

Conventional Vehicle	UDDS	FTP	HWFET	NEDC
Fuel Consumption (L/100km)	5.9	5.8	4.4	6
HC (grams/km)	0.365	0.281	0.284	0.401
CO (grams/km)	1.564	1.182	0.961	1.371
NOx (grams/km)	0.258	0.215	0.259	0.245

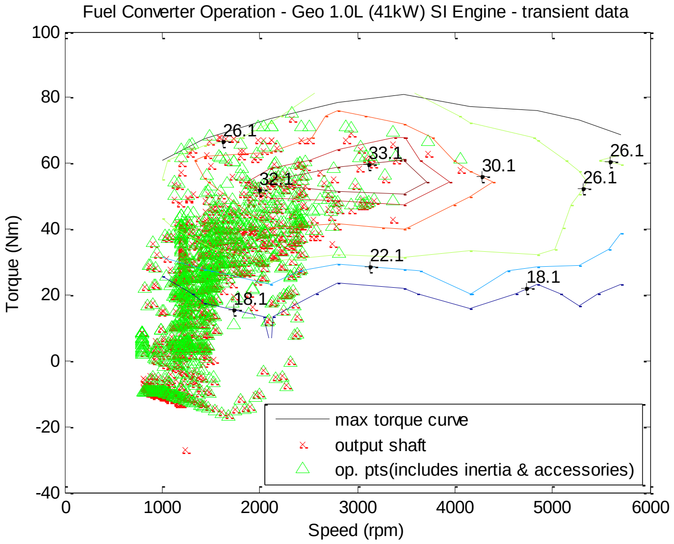

Fig5. Working points of a combustion engine of a conventional vehicle during simulation on the UDDS driving cycle

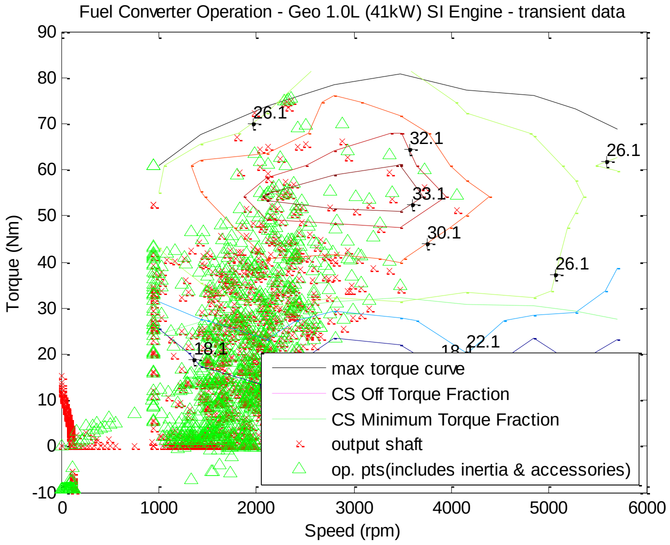

Fig6. Diagram showing the working points of a combustion engine of a conventional vehicle during simulation with a specified gear number on the UDDS driving cycle

3. Results and Discussions

Table 3 shows the results of simulation for a conventional vehicle and Figures 5 and 6 demonstrate the working points of a combustion engine of a conventional vehicle during simulation on the UDDS driving cycle.

According to the obtained results, as indicated in Figure 9, which compares the fuel consumption in a conventional vehicle and in a parallel mild hybrid vehicle based on this strategy, in all the driving cycles, the fuel consumption in the parallel mild hybrid vehicle is less than in a conventional vehicle. The reason for this can be found in the diagrams showing the working points of a combustion engine during a driving cycle. For example, the working points of a combustion engine during a UDDS cycle for a conventional vehicle and a parallel mild hybrid vehicle are presented in Figures 5 and 7. As can be seen in these two diagrams, the accumulation of working points in a combustion engine of a parallel mild hybrid vehicle is significantly under the influence of auxiliary electric control strategy in the range of high efficiency, while the working points of an internal combustion engine of a conventional vehicle is in a range with low efficiency.

Table 4: Results of simulation for a parallel mild hybrid vehicle

Mild Hybrid Vehicle	UDDS	FTP	HWFET	NEDC
Fuel Consumption (L/100km)	5.1	5.3	4.1	5.2
Fuel Consumption Reduction (%)	14	9	7	14
HC (grams/km)	0.307	0.242	0.231	0.329
HC Reduction (%)	16	14	19	18
CO (grams/km)	1.352	1.084	1.049	1.559
CO Reduction (%)	14	8	-9	-14
NOx (grams/km)	0.209	0.184	0.168	0.174
NOx Reduction (%)	19	15	35	33

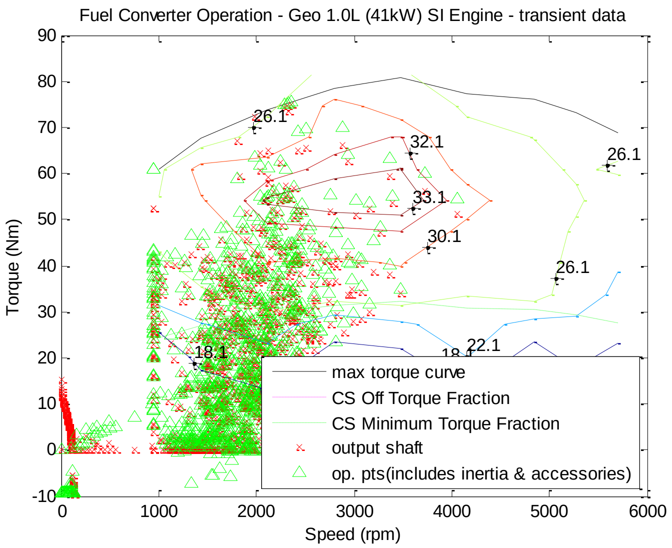

Fig7. Working points of a combustion engine of a parallel mild hybrid vehicle under an electric control strategy during simulation on the UDDS driving cycle

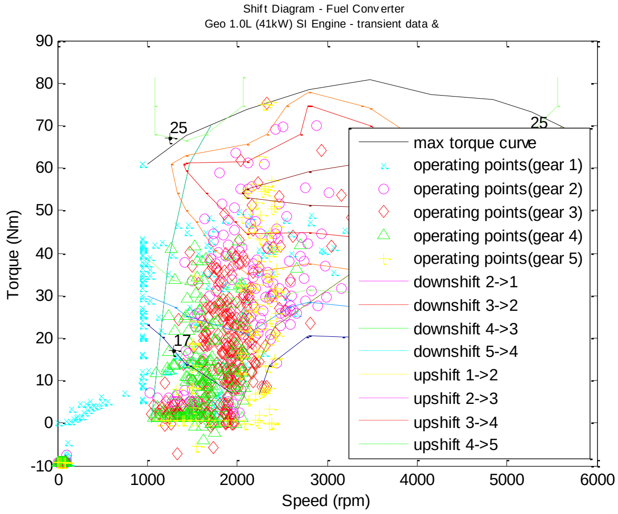

Fig8. Working points of a combustion engine of a conventional vehicle with specified gear number on a UDDS driving cycle

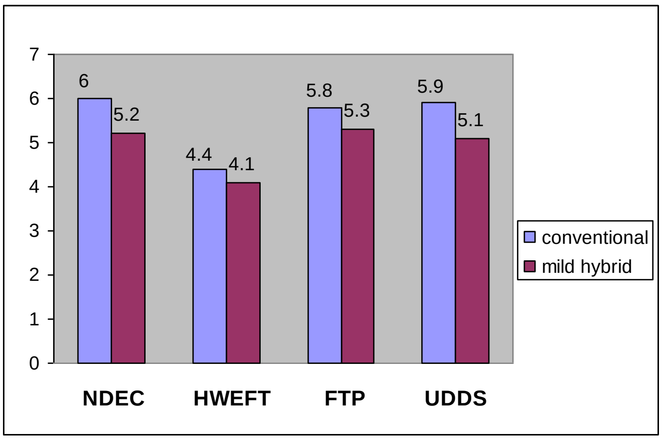

Fig9. Comparison between fuel consumption in a conventional vehicle and in a parallel mild hybrid vehicle based on auxiliary electric control strategy

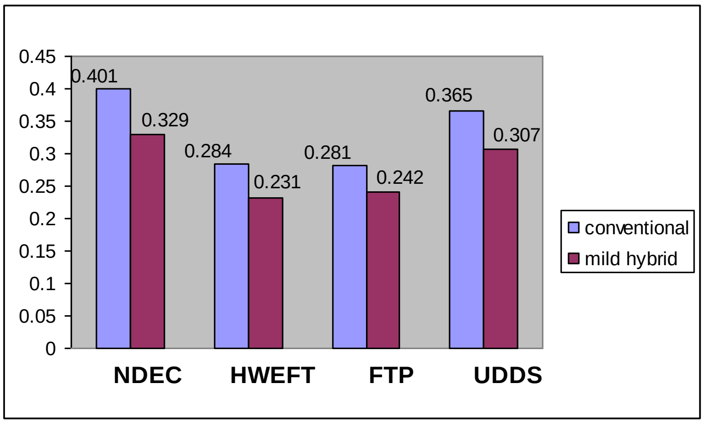

Fig10. Comparison between HC pollutant production from simulation of conventional and parallel mild hybrid vehicle under auxiliary electric control strategy

Comparison between pollutants show that the production of pollutants such as HC and NOx in Figures 10 and 12, is less in a parallel mild hybrid vehicle compared to a conventional vehicle, but, the relative production of CO pollutant in Figure 11, produced by two conventional and mild hybrid vehicles are different in various driving cycles.

The results obtained from Figures 9 to 12 indicate that fuel consumption and contamination in mild hybrid vehicles is significantly less than conventional vehicles. These digits are even more acceptable than environmental standards. Although, in Figure 11, the amount of CO pollutant in two driving cycles of HWFET and NEDC is more than in conventional vehicles which is related to too much reduction in the production of NOx pollutant in the case of mild hybrid vehicles for the two stated cycles. According to combustion reactions, it can be deduced that with the increase of temperature, there is an inverse relationship between the production of NOx and production of CO because combustion reactions have an inverse relation with temperature change. From Figure 13 it can be understood that, the mild hybrid vehicle demonstrates the desired speed with a high precision and does not have any problems in going through different cycles.

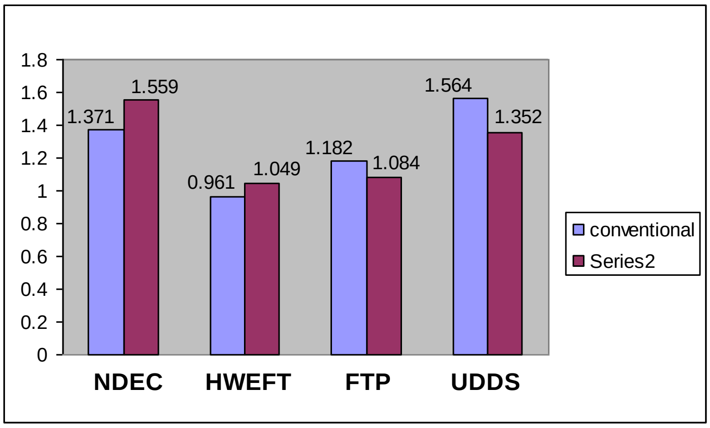

Fig11. Comparison between CO pollutant production from simulation of conventional and parallel mild hybrid vehicle under auxiliary electric control strategy

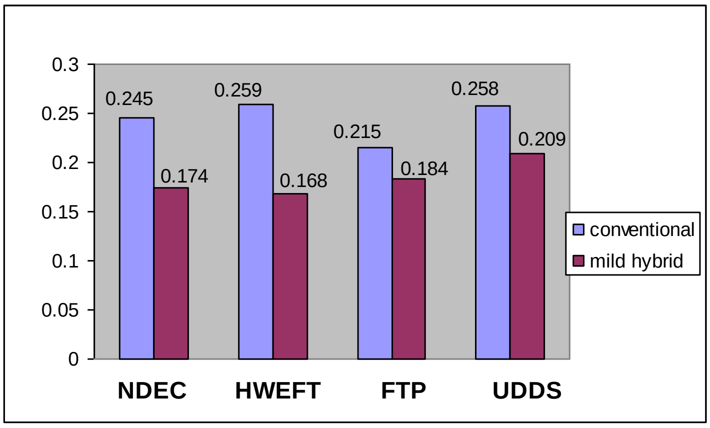

Fig12. Comparison between NOx pollutant production from simulation of conventional and parallel mild hybrid vehicle under auxiliary electric control strategy

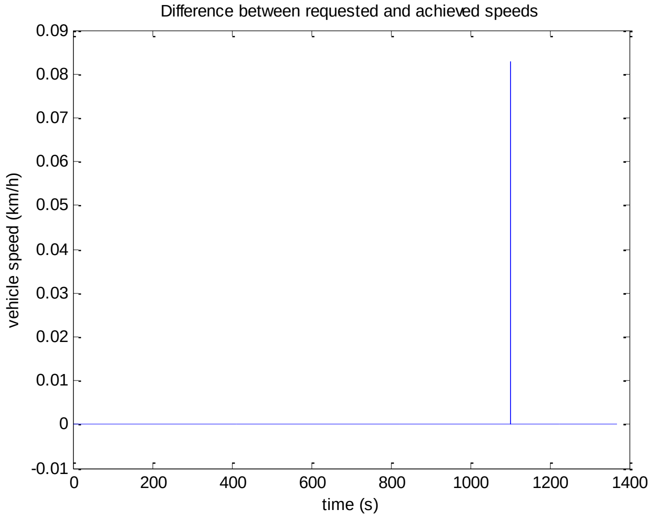

Fig13. Diagram showing the difference between the desired speed and the given speed by the mild hybrid vehicle on a UDDS driving cycle

4. Conclusions

Based on the results from this research, it can be stated that the effect of control strategy in mild hybrid vehicles results in a higher thermal efficiency, lower fuel consumption and pollution relative to conventional vehicles. This vehicle has been investigated in driving cycles of UDDS, FTP, HWFET and NEDC. The results show that with an increase in speed and acceleration in a driving cycle, fuel consumption is increased. Additionally, fuel consumption is increased and therefore efficiency is reduced as a result in driving cycles due to frequent stops. Design and manufacture of mild hybrid vehicles is possible through making small changes in the design of an internal combustion vehicle. There have not been a noticeable number of researches on commercialized full hybrid vehicles in Iran and it seems that focusing on this subject, not only has the advantages of cost reduction and use of existing internal combustion vehicles, opens the way for pollution reduction and optimization of fuel consumption followed by a step forward towards progress and improvement in design and manufacture of full hybrid vehicles in the future.

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