Design an Energy Management Strategy for a Parallel Hybrid Electric Vehicle

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Abstract

Nowadays, according to the air pollution dependence to cars and limitations of fossil fuel, car companies take a significant step to deal with such problems among which hybrid electric vehicles can be inferred. One of the more common software which is used for simulating hybrid electric vehicles is the ADVISOR. Thus, in this paper, first the vehicle model is chosen in the ADVISOR simulator and the required information about the vehicle and the driving cycle is derived from this simulator. In order to reduce the cost of parallel hybrid electric vehicle, a new fuzzy-based control strategy is proposed. Also, in order to better provide the driver's demand a proportional controller is used. Finally, the results obtained from fuel consumption, battery state of charge and output pollution for a standard driving cycle in Urban Dynamometer Driving Schedule (UDDS) and Extra- Urban driving cycle (EUDC) is presented and compared with those obtained from other energy management methods. The results denote the ability of the designed controllers at improving the considered costs.

Keywords

hybrid electric vehicle, electric motor, internal combustion engine, energy management, fuzzy compensator

1. INTRODUCTION

Air pollution in big cities has been a critical problem for many years. Technical research reveals that the main cause of city pollution is vehicles with an Internal combustion engine. Conventional vehicle has many disadvantages such as depending to a certain type of energy (oil), producing toxic gases like CO, CO_2, and NO_2, greenhouse gases like CO_2, noise pollution, and low efficiency and as a result loss of energy [Lachhab and Krichen, 2014].

According to the above statements, electric vehicles were proposed in 1890 decades and were popular until 1930. By developing in the vehicle manufacturing technology, and increasing the number of conventional vehicles, the need for clean vehicles or vehicles with less pollution is more sensed.

Thus, in Europe and America, laws were enacted which force car companies produce vehicles with less pollution, on the other hand, due to the decrease of petroleum fuel sources, some factors must be taken into consideration to maintain these important sources of energy [Gobczyński and Leroux, 2011].

By oil crisis in 70 decades and the Persian Gulf War, dependency to fuel make industrial countries to become more concerned. These countries decided to reduce the fuel consumption and increase the efficiency and performance of energy-consuming components.

Researches about fuel consumption reveals main factors of fuel consumption, thus programs were applied to control the fuel consumption and increase the efficiency of using fossil fuel such as the plan for increasing the efficiency of vehicles available in transportation, heating

convertors and distributed generation plants. Vehicles available in countries make much pollution because they apply ICE and use fossil fuel; these vehicles also have low efficiency in practice. Thus, governments attempt to improve the efficiency and performance of vehicles by persuading and protecting car companies at designing vehicles with higher efficiency. Companies such as Toyota, General Motor and ... tried to make electric vehicles and Hybrid Electric Vehicles [Ehsani et. al., 2009].

By improvement of technology and the use of more advance batteries and the production of more efficient electric motors and ICEs, vehicles were introduced to markets to overcome some of the problems involved.

By creating multi-direction electric drives, charge and charge depletion of such vehicles were possible through the electric grid that finally leads to generation of Plug-in Hybrid Electric Vehicles. These vehicles were more efficient and effective than conventional vehicles and as a result gained much interest throughout the world.

But nowadays, experience proved that pure electric vehicles are faced with many limitations in spite of many advances in this field and can be used in limited driving distance and just for special applications. In recent years the set of above factors makes the research to tend to the HEVs [Xiaomin, 2013].

2. ELECTRIC AND HYBRID ELECTRIC VEHICLES (HEV)

In many countries, one of the most important sources of fuel consumption and pollution production is the transportation navy. Due to the low efficiency of these vehicles' engine, the fuel consumption is increased, on the other hand due to inappropriate tuning of the engine and its large size, the pollution production rate is nearly in its large amount.

Thus, HEVs with more optimal fuel and energy are a good choice for a better and more appropriate transportation and produce less pollution with respect to conventional vehicles [Gong et. al., 2008].

One advantage of HEV is improvement of fuel consumption and reduction of greenhouse gases. The required propulsion force in HEV is supplied through two or more sources of energy. For example, ICE and electric battery, electric battery and fuel cell, electric battery and ultra-capacitor [Ehsani et. al., 2009]. SOC estimation for batteries is discussed in many literatures [Hamada et. al., 2011].

Using secondary sources of energy (energy storage device in these vehicles) leads to minimization in the size and power of the ICE in HEVs and provides more effective power in comparison with conventional vehicles in terms of acceleration and energy storage and break [Ehsani et. al., 2009].

2.1 Parallel hybrid electric vehicles

The parallel HEV is basically composed of a generation cycle parallel with an energy source. In this configuration, ICE is connected to the wheels through the gearbox and is limited by rotation of gears.

Thus ICE load is directly related to the variable power demand, and the electric system is also used to drive the vehicle. When maximum force is needed both of them are applied to deliver the force to the wheel. In parallel HEV, two force actuators namely ICE and electric motor are required. The advantage of this configuration with respect to series hybrid structure is that a smaller ICE and a smaller electric motor are used for optimal performance as long as the battery is not charging depleted.

In this paper Ford scape model is extracted from ADVISOR (Advanced vehicle simulator) as a parallel HEV. This model is illustrated in Figure 1.

3. FUZZY RULE- BASED METHODS

The hybrid drivetrain is nonlinear and time invariant thus fuzzy logic is seemed to be the best approach for solving the problem. In fact, instead of using certain rules, decision making feature of fuzzy logic can be gained. In the other words, fuzzy controller is the improved version of ordinary rule-based controllers.

Many researches are performed to minimize the PHEV's costs. Most of the researchers performed in this field focus on the minimization of the fuel consumption and pollution rate. However, improvement of battery charge is another factor that must be taken into consideration. The goal of the present paper is minimization of the vehicle's cost considering three factors of fuel consumption, battery state of charge and pollution rate using an appropriate method. By studying relevant papers and according to the above statements, it seems that fuzzy controller is more effective in minimization of the above costs.

Most of these researches try to solve the problem by considering the present situation of differential speed and torque demand from sources of energy and battery charge situation, according to the correct style of performance in HEV. However, by choosing the inputs and outputs of fuzzy controller more appropriate, the vehicle costs can be more reduced.

On the other hand, in the ICE sudden changes of speed

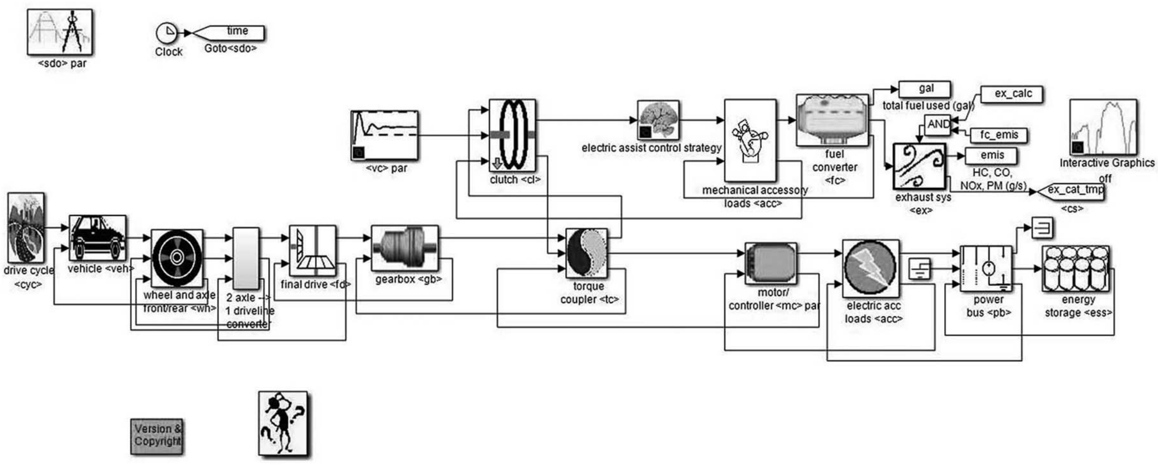

Fig. 1 Parallel hybrid electric vehicle model [ADVISOR, version 2003]

and torque lead to increment in the fuel consumption. Thus, not only the present driver's speed and torque demand are considered in the controller, but also, the variation trend of speed and torque demand with respect to previous situation is considered as the other inputs of the fuzzy controller.

According to this property and other characteristics of each source of energy in HEV; a fuzzy controller is used in this paper beside a torque coupler in order to implement necessary momentous changes in the value of speed and torque which is demanded from each source of energy. Also, in order to better provide the driver's force demand, a proportional controller is used.

In [Yushan, 2010], a fuzzy control strategy is proposed for a parallel hybrid electric bus. A rule-based strategy is proposed in [Lee and Sul, 1998] for a parallel HEV to optimize the performance of combustion engines. In order to optimal design of fuzzy rule based controller the genetic algorithm is used. An energy management strategy is proposed in [Gao and Ehsani, 2010] for a parallel HEV in order to trade-off between reducing fuel consumption and NOx emission.

4. DRIVING CYCLE

Driving cycles are speed-time curves which are created for evaluating the amount of fuel consumption and pollution and for simulating vehicles. Also, they denote traffic and driving situations in different areas. Using driving cycle, driver's behavior is modeled and performance of ICE, power transfer system, electrical system and batteries are predicted.

In this paper, two standard driving cycles in UDDS (Urban Dynamometer Driving Schedule) and EUDC (Extra- Urban driving cycle) is investigated as a simulated driving cycle. These drive cycles are illustrated in Figure 2 and Figure 3 respectively. The information

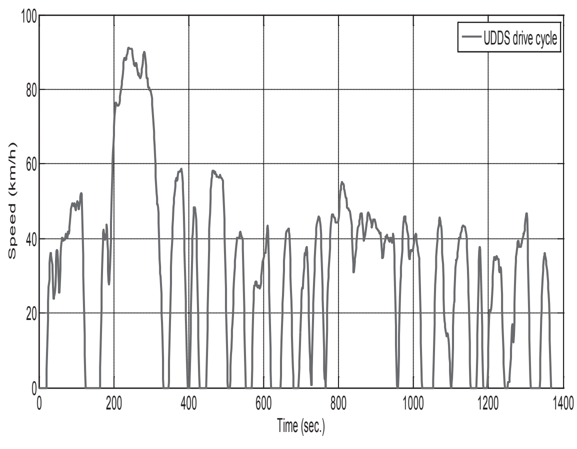

Fig. 2 Urban dynamometer driving schedule (UDDS) [ADVISOR, version 2003]

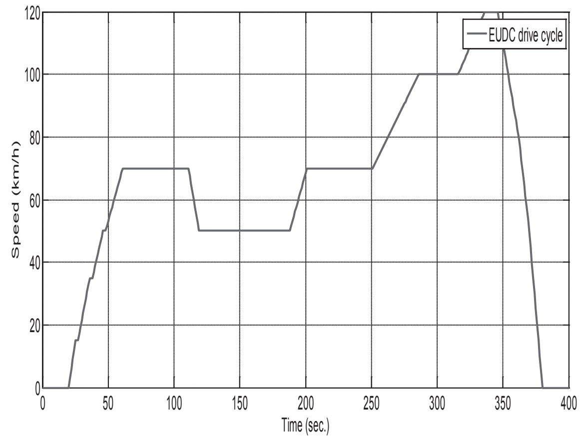

Fig. 3 Extra-urban driving cycle (EUDC) [ADVISOR, version 2003]

Table 1 Information of UDDS [ADVISOR, version 2003]

Time (s)	400
Distance (km)	6.95
Maximum speed (km/h)	120
Medium speed (km/h)	62.44
Maximum acceleration (m/s2)	0.83
Minimum deceleration (m/s2)	-1.39
Mean acceleration (m/s2)	0.38
Mean deceleration (m/s2)	-0.93
Idle time (s)	42
Number of stops	1

Table 2 Information of EUDC [ADVISOR, version 2003]

Time (s)	1369
Distance (km)	11.99
Maximum speed (km/h)	91.25
Medium speed (km/h)	31.51
Maximum acceleration (m/s2)	1.48
Minimum deceleration (m/s2)	-1.48
Mean acceleration (m/s2)	0.5
Mean deceleration (m/s2)	-0.58
Idle time (s)	259
Number of stops	17

involved with these two cycles is depicted in Table 1 and Table 2 respectively.

5. PROPOSED FUZZY LOGIC STRATEGY

Fuzzy theory is first introduced by Professor Lotfi Zade in 1965. This method is appropriate for nonlinear systems with time-variant parameters. Structure and parameters are two main factors in the design of a fuzzy controller.

In this paper, Mamdany implication is used in the design of the compensator and a Gaussian function is applied for defining the membership function.

The optimal performance range of ICE is in the speed of 1500 to 3500 radian per minute and in the output torque of 60 to 100 Newton-meters. Similarly, the electric motor has its best performance for the torque in the range of lower than 150 Newton-meter. The best range of battery charge and charge depletion is in the medium SOC (State of charge) mode and for the value of between 0.55 and 0.65.

In the proposed compensator, the demand speed and torque of gear box from Torque coupler, the previous momentary value of the speed and torque demand of gear box from Torque coupler and the value of SOC are considered as input variables. Also, the required changes of speed and torque demand from each electric motor and combustion engine are considered as output variables.

When the battery charge is low, if the driver's speed and torque demand is also low, the control law must be arranged such that ICE performs in its optimal performance. If the driver's speed and torque demand are medium or large, ICE must deliver more power in order to provide both driver's demand and battery charge.

When the SOC is medium, if the value of driver's speed and torque demand is low, ICE must be off. In the other words, it delivers no power. If the value of driver's speed and torque demand is large, control laws must be arranged such that ICE performs in its optimal range. In this case, if ICE could not be able to provide the driver's power demand by itself, the required additional power is provided by electric engine.

When the SOC is high, if the value of driver's speed and torque demand is low or medium, ICE must be off. In this case, the vehicle operates as a pure electric vehicle. If the value of driver's speed and torque demand is medium or large, the control laws must be arranged such that ICE operates in its optimal range. In this case, if the ICE could not be able to provide required power by itself, the additional required power is provided by electric engine.

The membership function defined for speed is shown in Figure 4.

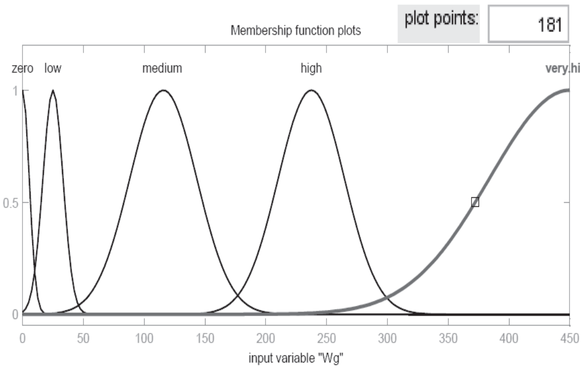

Fig. 4 Membership function defined for speed

6. EVALUATION OF FUZZY AND PROPORTIONAL COMPENSATORS

In this section, for each considered factors simulation is presented for a parallel HEV in Advisor simulator in order to evaluate the performance of the designed controller. The simulation results involve the comparison of fuel consumption, battery SOC and the emission rate of each pollutant in the presence and absence of designing controllers.

6.1 Costs in UDDS drive cycle

6.1.1 Vehicle fuel consumption

Figure 5 shows the total fuel consumption of the vehicle before and after applying the compensator. It can be seen that the proposed controller reduces the fuel consumption to about 51.86 percent with respect to the case without compensator.

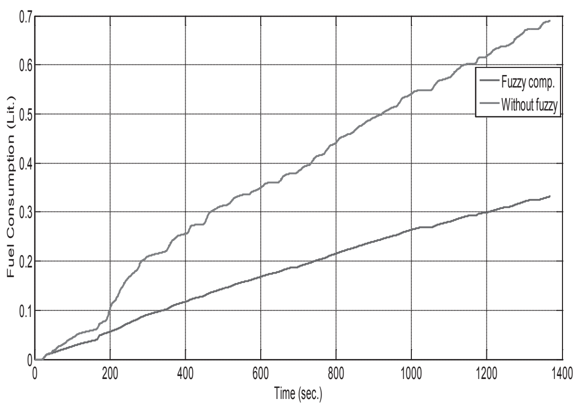

Fig. 5 Fuel consumption curve in the presence and absence of these two compensators

6.1.2 Battery state of charge

Figure 6 illustrates the variation of the battery charge situation. In this case the remained SOC of the vehicle at the end of the path has improved to about 32.93 percent.

6.1.3 Pollutant dispersion rate

It can be shown that the dispersion values of HC, CO and NO_x pollutants in the presence of compensator have been decreased to about 20.53, 17.12 and about 60.32 percent respectively.

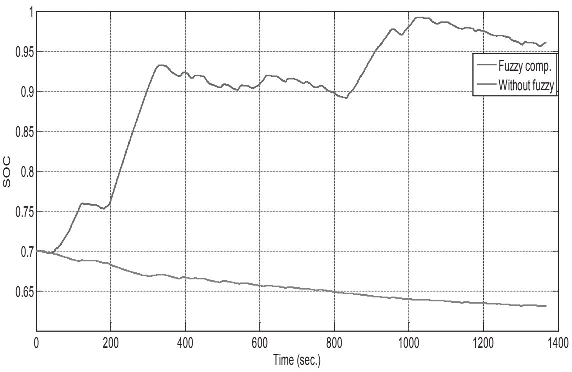

Fig. 6 Battery SOC curves in the presence and absence of the two compensators

6.2 Cost investigation in EUDC drive cycle

In this section, performance of proposed compensator is investigated in the EUDC driving cycle.

6.2.1 Fuel consumption

The total fuel consumption of the system before and after applying the compensator is illustrated in Figure 7. The upper and lower curves are corresponding with the fuel consumption in the absence and presence of compensator respectively. It can be seen that the fuel consumption can be reduced to about 8.95 percent using the designed controller in comparison with the case without using the compensator.

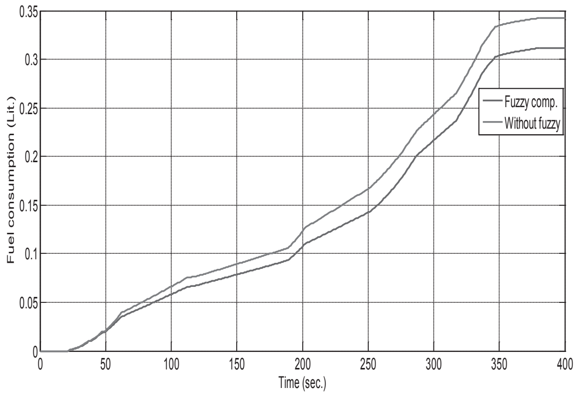

Fig. 7 Fuel consumption curve in the presence and absence of the two controllers

6.2.2 Battery charge situation

Figure 8 illustrates the variation trend of battery state of charge. The rest of the SOC is improved to the 0.48 percent at the end of the path.

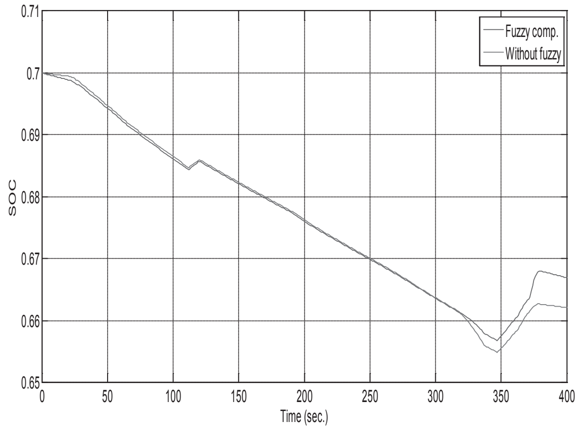

Fig. 8 SOC curves in the presence and absence of the two compensators

6.2.3 Pollutant dispersion rate

It can be demonstrated that the dispersion values of HC, CO and NO_x pollutants in the presence of compensator have been decreased to about 0.22, 9.99 percent and about 10.59 percent respectively.

Table 3 deals with a comparison between the results achieved from the present research with those obtained from previous researches.

7. CONCLUSION

In this paper, a fuzzy compensator is applied in order to reduce the costs in a parallel HEV. Also, a proportional controller is used to better satisfy the driver's demand. The fuzzy compensator optimizes the power distribution between electric motor and combustion engine. It is shown that more favorable performance is achieved by using both these controllers for a parallel HEV.

The designed controller not only helps to better provide the driver's required power, but also plays a significant role in the reduction of fuel consumption and pollution rate while improving the battery charge

Table 3 Comparison between present and previous researches

	[Lee and Sul, 1998]	[Poursamad and Montazeri, 2008]	[Schouten et al., 2002]	[Baumann et al., 2000]	[Syed et al., 2008]	[Zhou et al., 2013]	Presented research
Fuel consumption	-	1.75	6.8	12.4	3.5	56.16	51.86
SOC	-	-	50	-	-	-	32.93
HC pollutant	-	8.52	-	-	-	56.16	20.53
CO pollutant	-	-16.42	-	-	-	-	17.12
NO_X pollutant	20	30.76	-	-	-	-	60.32

situation.

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