

# Reducing the Fuel Consumption and Pollution by Designing the Optimal Energy Management in Hybrid Vehicles

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## Abstract

**Objective:** One of the main factors in fuel consumption and pollution is transportation and automotive industry. Today one of the most effective methods to deal with pollution and fuel consumption is developing the hybrid electric. **Method:** This type of propulsion system has been used of two combined power sources of the internal and electric combustion engine alongside each other for providing the required power to drive the vehicle and in addition to that, they remove each other's limitations by using the overlapping simultaneously. **Results:** One of the main important parameters in optimal hybrid vehicles performance is the energy management system appropriate designing between the power sources that it is the main factor in optimal performance of hybrid vehicles. Therefore, in this research, first the hybrid vehicle modeling is presented, including the combustion engine, gearbox, electric motor and battery with the association of Advisor-Simulink. Then, the optimal energy management system is designed for the optimal distribution of power between the combustion and electric engine according to the fuzzy logic. **Findings:** It shows that it can be reduced the fuel consumption and pollution by using the electric auxiliary power source along with combustion engine and optimal energy management in different conditions. **Applications/Improvements:** Finally, the sensitivity analysis of the effect of weight on vehicle performance will be assessed.

**Keywords:** Battery, Combustion Engine, Electric Engine, Energy Management System, Fuel Consumption and Pollution, Hybrid-Electric

## 1. Introduction

Governments, industries and researchers have been tried to enhance a proper replacement for conventional transportation means, due to objectives like air pollution and prices rising of fuels. It is predicted that the HEVs are as one of the important automotive industry technologies.<sup>1,2</sup> So, the researchers are essential in the field of hybrid vehicles and their developing and manufacturing. Also it should be considered that, producing the carbon dioxide has been come to more than 1,000 million tons just in the Union of Europe as the main pollutant gas, according to the Union of Europe's report in 2014 that in the case of the lack of taking the necessary measures will come to more than triple in 2050.

EIA has been presented the value of fuel consumption and pollution for different industries, according to Figure 1.<sup>3</sup>

As it is known, the share of transportation industry is almost 26% of fuel consumption and 34% of the emissions in the whole world.<sup>4</sup> In conventional engines, 14.5% of the whole fuel power is spent to move the vehicle and its components, according to the official announcement of USDE. While most of the energy, is distributed as heat and is a reason for warming and emissions, in the combustion process. However, the electric engine spends 75% of its power to drive.

Today, according to the pollution generated via transportation industry, and limitations of fuels, automotive factories have taken a main process in dealing with this matter that it can be referred to Hybrid Vehicle, Fuel Cell,

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GDI, HCCI and Bi-fuel. High efficiency, low pollution, high measurable distance, optimal safety and reasonable expense with conventional drive systems are among the significant characteristic for hybrid transportation system. Studies conducted to show that the controlling strategy has the greatest effect on the performance of the power transmission system in hybrid vehicles.<sup>5-7</sup> In the reported article showed that fuzzy control strategy designing can be effective in energy management of parallel HEV and decrease the fuel consumption and pollution up to 15%.<sup>7</sup>

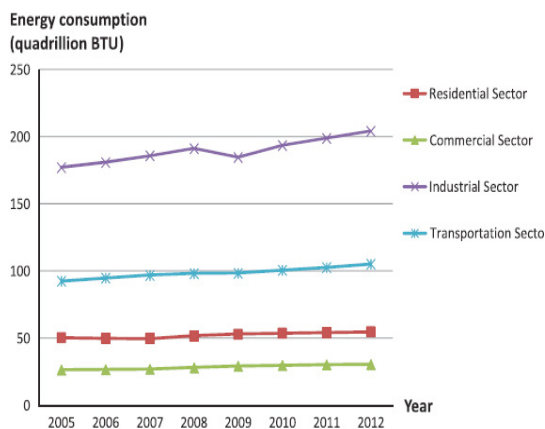


Fig. 1. The delivered energy consumption (Quadrillion BTU) based on different end-users.

Figure . Fuel consumption in various industries.

Also in several studies, the optimal controlling strategy has been considered for the energy management that due to high calculations volume it is not applied.<sup>8-10</sup> Therefore, in this paper, first fuzzy controlling strategy is designed with the series structure for the HEV and the performance simulation of combustion engine, electric engine and battery are presented during the actual driving cycle to analyze the reduction amount of fuel consumption and pollution in different situations.

## 2. Electric-Hybrid System Parts Modeling

Hybrid power trains are as the type of generalized pure electric that their pure electric disadvantages are largely removed to some extent and it could be determined the internal combustion engines disadvantages are removed. The main advantages of this system of power transmission is function in speed and fixed load compared to conventional engines, and so-called they work in their optimal points that this would increase the engine performance

and reduce the pollution and lower the fuel consumption. In addition during braking, energy is saved in batteries electrically, through a Regenerative Braking system, and this makes less the function of combustion engine which as a result reduce the pollution and to come down the fuel. HEVs include various structures.<sup>11</sup> However, necessarily a hybrid vehicle has been made of an energy management unit, a power production unit and a power transmission system (Figure 2).

- Internal combustion engine: the existed engine in Hybrid vehicles, is very alike the engines in conventional vehicles. But this engine is down-sized and takes the advanced technologies to conventional cars that reduce pollution and improves performance. Figure 3 illustrates the classification of types of power transmission system in terms of the amount of hybridization.

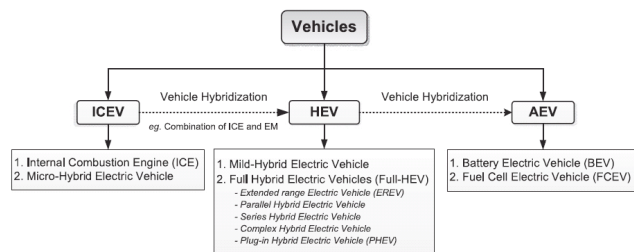


Figure 2. Classification based on the hybridization degree.

- Electric Engine: In hybrid vehicles, it is capable to work both as an engine and a generator. In instance, when this engine is needed, the engine will be able to make the speed by using the batteries and when the vehicle does not require the electric engine, for instance, when it is moving in a downhill, this electric engine returns energy to the batteries like a generator.
- Energy Storage System: In Hybrid vehicles, it can be flywheels, batteries, hydrogen fuel and ultra-capacitors. Battery is the main expanded energy storage one. The most important feature of the battery is its capability that is evaluated via ampere-hour. Also, the stored energy in battery is of the main features of the battery (capacity on mean of voltage in emptying the battery) that it is determined according to the watt-hour. Another parameter that is effective in the performance of the battery and its choice is State-of-Charge

**Table 1.** Types of batteries

Electric engine(Kw)	Fuel cell		Ultra Capacitor		Capacity (KWh)	System voltage	Hybrid degree
	Maximum power (KW)	Energy (Wh)	Maximum power (KW)	Energy (Wh)			
-	-	-	-	-	-	12	Conventional
3-5	-	-	6	30	0.02-0.05	12-42	Micro Hybrid
7-12	-	-	35	100-150	0.125-1.2	150-200	Mild Hybrid
40	-	-	-	100-200	1.44	200-350	Full hybrid
30-70	-	-	28-45	100-200	6-20	300-500	PHEV
50-100	50-100	150-200	28-45	300	20-40	300-500	AEV

(SOC) that is defined as a ratio. Sufficient batteries have been illustrated in Table 1.

Batteries on the basis of material and type of their performances are classified in five structures of Nickel, Acid, Lithium, Air insulation and ZEBRA batteries. Acid battery is the cheapest and most available batteries in conventional vehicles. These batteries, in the production and usage process, cause the environment emission and are not utilized in hybrid vehicles, in addition to having the high weight.<sup>12</sup> Nickel ones have the heavy weight, high maintenance costs and high discharge rate, although they are environmentally. Zero-pollution batteries have high temperature feature in the range of 350-500°C that has been made of sodium-nickel chloride. They have longer State-of-Charge and life than other batteries, but they lose energy of 90w, when they not in use. Lithium batteries are considered the most widely used batteries in Hybrid vehicles with longer age, light and high SOC energy. Further, the Lithium batteries material is not of toxic substances like lead or cadmium. However the high expense of production of these batteries is one of its detriments. Today, Lithium-sulfur battery has the highest power to the low weight among the Lithium batteries. Lithium Polymer battery has the high compliance capability for locating and different safety coefficients, but provides the lower conductivity and power energy.

Another one of the lithium batteries is lithium-iron-phosphate battery that has higher charge and discharge current and chemical and thermal characteristics along with it that shows the better protection properties. Its deterrent contains the large volume, properties of its low energy and life span. That nowadays a lot of researches are conducting for commercialization of this type of battery.<sup>12</sup>Power transmission system: power transmission system, can be kept on, automatic and automatic-manual

in hybrid vehicles. Its type of power transmission process and optimization can play a main role in fuel reduction and HEV efficiency.

- The control unit: The objective of the control theories in HEV is optimal energy management, emission reduction and fuel economy, displacement of combustion and electric engine work-points and the battery to fields via most efficiency for achieving the aims and achieving the capability of driving the vehicle.

## 2.1 Hybrid Electric Vehicle Controlling Strategy

As it was previously mentioned, in hybrid vehicles are used of several power produce sources for producing the required power. One of the important existed challenges in designing the hybrid vehicles is the way of managing resources of power production in these vehicles. The way of managing these resources has a direct effect on fuel consumption and pollutions and also, the dynamic performance of the vehicle. Generally there are two kinds of controlling strategies for hybrid controlling procedure, Rule Based (RB), Optimization technique.

According to the empirical data, mathematical pattern, determined features and load balancing strategy in the vehicle that is classified into 2 groups of certain and fuzzy control. On/off control is considered as one of the primary controls and with high certainty that is utilized as the Advisor. Controls with optimization procedure are used of numerical resolving for reducing the intended function (fuel economy, pollution and or steep). That among them, it can be referred to Linear programming control, Dynamic programming.

Generally the strategic control of power flow is classified into three-step of battery discharge mode, battery charge and braking. In the first mode, as in Figure 3, battery has been operated as the initial origin of power and when the intended energy is exceeded the capacity of battery, the internal combustion engine is enabled for energy compensation. In next step, in battery charge, the generator/internal combustion engine will be determined as a power source. While SOC to be less than the required minimum, the internal combustion engine uses extra power to charge the battery. At the procedure of the waste energies recovery, the energy recovery procedure becomes active to recycle braking energy and damping of suspension system. When the Recycled Power is more than the amount needed to save, it is disappeared as the friction.

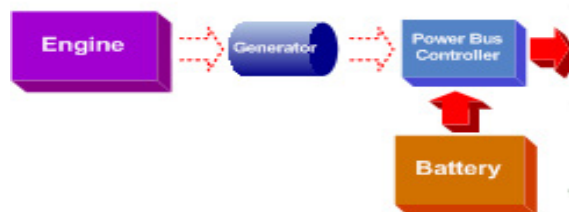


Figure 3. Energy flow in the start level.

Controlling strategy in hybrid vehicles is an algorithm that determines how the energy or power is produced, consumed and saved in the vehicle. Controlling strategy determines each of the energy sources how to behave, such as combustion engine, electric engine and battery, at the moment, according to the existed data and received signals from the various parts of the vehicle. Controlling strategy should manage the energy sources in a way that the driver's orders are performed exactly and while the overall performance of the controlling strategy should be in a way that the fuel consumption amount and output pollutants are reduced and the vehicle's functional capabilities are maintained.

Fuzzy control provides the possibility of entering the Intuitive understanding and knowledge and designing experience as the linguistic variables in the controller. In addition, this method has high flexibility and ability in adjusting and optimizing the parameters. Rules and fuzzy control parameters are determined according to the knowledge of designer. The used logic in designing this Fuzzy controller is the idea of balancing the load. In

balancing the load method, the combustion engine is as the main source of power and electric engine is used as the auxiliary source. In this controlling strategy, it will be tried that the combustion engine work-point be optimum at any moment. According to this, the optimal combustion engine torque has been calculated at any speed according to the defined performance criteria.

Fuzzy controller corrects the optimal torque and calculates the output torque of the combustion engine, according to the command torque and state-of-charge at any moment. Difference between the output torque of the combustion engine and required torque is provided by the electric engine. The combustion engine torque is determined in a way that the driver's orders, be performed continuously which are applied by using the gas and brake pedals, and also, the state-of-charge always stay in an acceptable range. The way of fuzzy controller performance has been shown schematically in Figure 4.

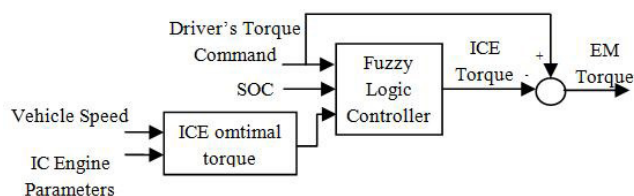


Figure 4. Fuzzy controller of hybrid electric vehicle.

Designed fuzzy controller is as the type of Mamdani here. Command Torque by the driver and state-of-charge constitute the inputs of fuzzy controller and of the ideal optimal torque in the combustion engine has been used only for normalizing the membership functions. Fuzzy controller output is not the normalized output torque amount of the combustion engine. Each of the inputs and outputs has three membership functions and the controller has nine fuzzy rules totally. Command torque is normalized with number between 0 and 1 that the number 0 indicates zero torque, 0.5 represents the calculated optimal torque for the combustion engine, according to the engine speed at the moment and 1 is the presented maximum torque by the engine combustion at this moment.

To normalize the command torque, this torque is compared with the optimal torque of the combustion engine at any moment. It should be noted that the optimal torque of the combustion engine - 0.5 is changed at any moment (Figure 5).

Similarly, State-of-Charge is also normalized between the number of 0 and 1, which 0 represents the minimum allowed state-of-charge and 1 represents the maximum allowed State-of-Charge.

Number of 0.5 is also consistent with the target of value of state-of-charge. The purpose value of state-of-charge has been selected equal to 0.65; due to charge and discharge curves and lead-acid battery. Designed fuzzy controller is of the type of Mamdani here. Command torque by the driver and state-of-charge, constitutes the fuzzy controller inputs and it has been used of the ideal optimal torque of the combustion engine only for normalizing the membership functions. Fuzzy controller output is the normalized amount in output torque of the combustion engine. The difference between the command torque and output controller torque is provided by the electric engine. In this controller has been used of minimum operator for the logical AND operator and the Fuzzy-removing method is used in the center of gravity. Each of the inputs and outputs has three membership functions and the controller has nine fuzzy rules totally. Command torque is normalized with the number between 0 and 1 that the number 0 indicates zero torque, 0.5 represents the calculated optimal torque for the combustion engine, according to the engine speed at the moment and 1 is the represent able maximum torque by the combustion engine in this moment.

		Required Torque		
		Low	Opt	High
SOC	Low	Opt	High	High
	Normal	Low	Opt	High
	High	Low	Opt	Opt

Figure 5. Fuzzy rules table.

To normalize the command torque, this torque is compared of with the optimal torque of combustion engine at any moment. It should be noted that the optimal torque of the combustion engine - 0.5 numbers - is changeable at any moment.

Similarly, state-of-charge is also normalized between the number of 0 and 1, which 0 represents the minimum allowed state-of-charge here and 1 represent the maximum allowed state-of-charge. 0.5 is also consistent with the target value of the state-of-charge.

## 2.2 Classification of the Hybrid Power Transmission System

Hybrid power trains are classified generally into 3 groups, according to the structure and required action: series, parallel and series-parallel (Combined).

### 2.2.1 Structure of Seri Hybrid

In this category of hybrid power trains, the combustion engine starts a generator then both charges the battery and both moves an electric engine and in this way, the power transmission is done. In the current system, direct combustion engine is not joined to the power train. It is named series, since the power has been utilized as series for driving and it is utilized for driving engines with less energy and optimal working range (Figure 6).

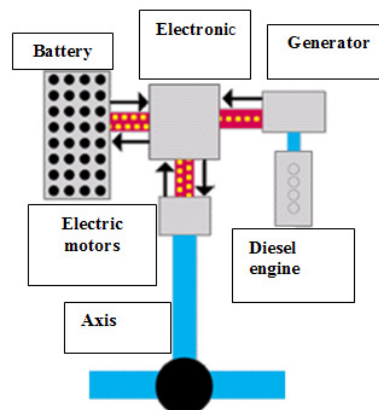


Figure 6. Series hybrid structure.

### 2.2.2 Structure of Parallel Hybrid

In this type of system, the mechanical and electric engines are moved the vehicle in parallel. So, the electric engine is fed by battery and the combustion engine is fed via fossil fuel sources directly. In this mode, the generator is removed and the battery is charged by changing mode of the electric engine to the generator. As this procedure has only an engine, the electric engine cannot charge the battery at the same time and causing the drive. Schematic shape of parallel hybrid configuration has been shown in Figure 7.

### 2.2.3 Series-Parallel Hybrid System

This plan is as a type that could be utilized in various conditions as parallel or series. It is possible to use the combustion system and electric system separately and simultaneously, by using the advanced technology. In this way, it can inde-

pendently be the combustion or a mix of the two systems, in urban cases of fully electric and with no pollution and in high speeds and in rural area. Both systems operate together, in situations such as rapid speed. Such systems are normally of combination type and by using an appropriate controlling strategy is practically with providing a good performance, state-of-charge is maintained in a good mode and there are two electric engines in this system, that it can be utilized of combination of them, depending on the conditions and they also have the capability to convert into the generator (Figure 8 and 9).

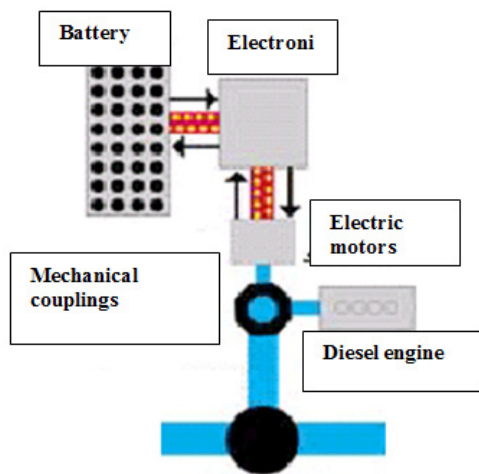


Figure 7. Parallel hybrid structure.

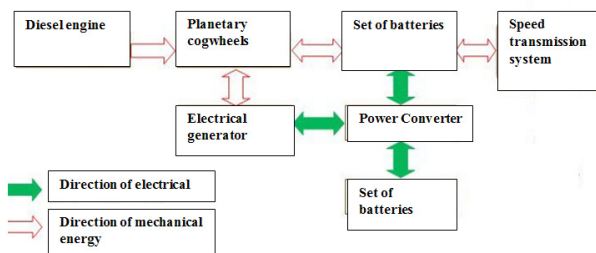


Figure 8. Combination structure.

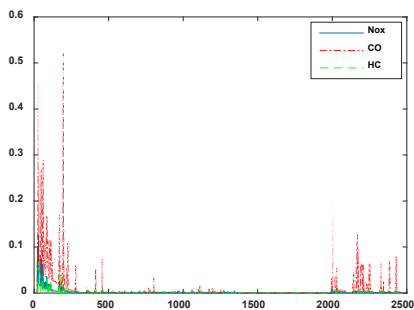


Figure 9. Releasing the pollution during FTP cycle.

In different moving conditions and based on the various criteria, there are compared three kinds of parallel, series, and blended in Table 2.

Another kind of HEV classification is defined according to the using amount of electric power. For the proper hybridization, it should be identified the optimal ratio of using of electric powers and internal combustion engine. So it can be reduced the fuel consumption and pollution, by using the optimal amount of this indicator in different situations. The degree of hybridization is defined as the rate of the consuming electric to the whole power.

### 3. Simulation and Results

This controller was performed on the hybrid riding vehicle with the series structure, actions and simulation for FTP driving cycle for evaluating the performance of fuzzy controlling strategy. For simulating the performance of software vehicle was used of ADVISOR. Work-points of combustion engine in the vehicle have been obtained by using the fuzzy controller during FTP cycle, that has been provided in the Figures of 9 and 10.

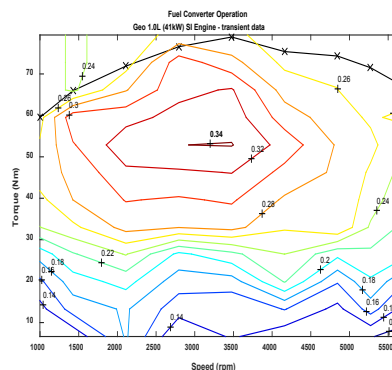


Figure 10. Combustion engine performance points.

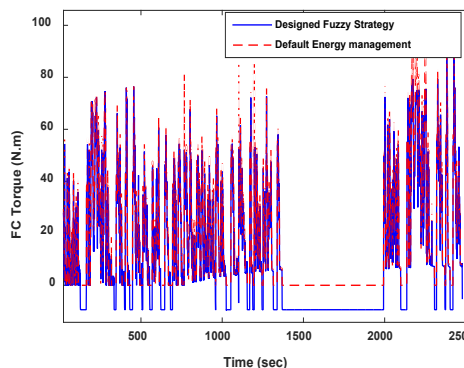


Figure 11. Comparing the generated torque of combustion engine.

**Table 2.** Comparing the performance of different types of hybrid structure

Driving performance			Improving the fuel consumption			Hybrid system comparison
Continuous high output	Acceleration	Total efficiency	High efficiency control	Energy recovery	Idling stop	
○	○	●	●	●	●	Series
○	●	●	○	●	●	Parallel
●	●	●	●	●	●	Series-parallel

: ● Very good , ●: good, ○: weak

In the next step, results have been compared for the torque of the combustion engine in Figure 11. Results shows, the combustion engine torque is reduced by using the fuzzy strategy and controlling strategy changes have been done in such a way that take the maximum power from the clean electrical power source. As a result, fuel consumption and pollution have been reduced effectively.

Finally, fuel consumption and pollution of hybrid vehicle have been compared with fuzzy strategy with conventional hybrid during FTP cycle that the results have been provided in Table 3. The results show that fuzzy can reduce the fuel consumption up 9% and reduce the pollutants emission to 7%.

**Table 3.** Comparing the fuel consumption and pollution

Improvement percentage	hybrid	conventional	Energy management strategy
9%	6.6	6	Fuel consumption (litr)
4%	0.267	0.257	HC (g/kW-hr)
8%	0.240	0.221	Nox(g/kW-hr)
10%	1.372	1.243	CO (g/kW-hr)

It's been estimated that hybrid-electric driving systems with fuzzy have the greatest effect on fuel consumption and CO pollution respectively to 10 and 9 percent. This saving in fuel consumption means low producing of harmful gases in lower speeds and low load, in addition to reducing the cost of vehicle consumption.

## 4. Conclusion

In this paper has been used of fuzzy logic controller strategy for energy management in Adviser software. So that

this strategy manages the State-of-Charge value ideally, in addition to improvement in fuel consumption and leads to reduce the fuel and pollutants. For evaluating the hybrid vehicle performance, first, the series hybrid vehicle modeling has been done and then, the performance of combustion engine, electric engine and battery as the energy storage system have been analyzed in the actual driving cycle by designing the fuzzy energy management. Results show that by appropriate making hybrid of power transmission system, it can be achieved to a better performance in terms of fuel consumption and pollution that is considered as an effective step in the production of clean energies in automotive and transportation indu

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