Reducing Fuel Consumption and Emissions with Optimal Sizing of the Power

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In this article, the aim is to apply and evaluate energy consumption management and emission reduction for hybrid electric vehicles. For this purpose, the modeling and sizing of the vehicle's transmission components is done and the performance of the vehicle is evaluated in the standard driving cycle. Based on the evaluation of the cost of fuel consumption for the distribution of different powers, it acts as a principle for choosing the optimal fuel performance point between the combustion engine and the electric engine. Also, the strategy for discharging the battery is examined, which is the strategy of charge depleting and charge sustaining (CDCS), in which the reduction or consumption of the battery charge is done first in a fully electric drive and then it operates in the charge enhancement mode. Then a comparison is made between the control strategy based on the role of CDCS and the sizing of the power transmission components of both battery discharge modes. Validation of the used methods is done using simulation in MATLAB space with the help of ADVISOR software and the results are analyzed

Keywords: hybrid-electric vehicle, power transmission sizing, vehicle modeling, ADVISOR, fuel consumption and emissions.

1. Introduction

Large-scale environmental problems, on the one hand, and bottlenecks related to fossil fuels, on the other hand, have caused hybrid vehicles (combustion and electric combination) as well as vehicles that work with fuel cells to replace combustion vehicles [1-3]. Therefore, today, in addition to the propulsion systems of internal combustion vehicles, a new category of three other systems has been formed, which are: electric vehicles, electric hybrid vehicles and fuel cell electric vehicles [4]. An electric hybrid vehicle is a type of electric vehicle that does not have the defects of ordinary electric vehicles. For example, electric vehicles must have large batteries. Secondly, they are regularly charged by the power transmission network, and this is the reason for their low efficiency. In hybrid vehicles, the power of their combustion engine can be used in the form of mechanical power or its storage in the form of electrical energy, so they have the ability to use alternative fuels and are not only limited to the use of fossil fuel [5]. In HEVs, combustion chambers are used in auxiliary power units to produce electrical energy with minimal pollution. HEVs use braking energy storage and help reduce energy loss while driving [6].

In the field of the effect of traffic and driving cycle on the rate of pollution and fuel consumption, laboratory research has been conducted in recent years [7], to study of the effect of traffic on the production of vehicle pollution has been presented and has investigated the effect of driving cycle and urban traffic on fuel consumption and pollutant production [8]. And in another article [9] with laboratory measurements, the values of fuel consumption and pollutants for different cycles have been determined for several sample vehicles [10]. In previous researches the effect of the control strategy [11-13] and traffic conditions [14-16] on HEVs performances has been evaluated. They found that in congested heavy traffic conditions HEVs efficacy is clearer and also, the optimal control strategy for state of charge of batteries and switching the engine and electric motor can reduce the fuel up to 25% in various conditions. In this paper a simulation model of the HEV developed and the sizing effect of the powertrain system by appropriate choice of the components are evaluated in real traffic condition.

2. Method

2.1 HEV configurations

Hybrid vehicle works with two different energy sources. The use of such a system actually preserves the efficiency of the internal combustion engine (ICE) and reduces pollution to the extent of the electric vehicle (EV). In order to obtain a good combination of ICE and EV, we need to use fuel cells and diesel or gasoline engines, along with batteries, flywheels, and high-capacity storage devices. In hybrid vehicles, three different structures or modes are used in the use of these two types of engines, which are: 1. Series 2. Parallel 3. Series and parallel (figure 1)

Flywheel: The flywheel is a means of converting electrical energy into kinetic (rotational) energy, which is made due to the rapid rotation in the engine structure. This device releases the energy stored in the form of kinetic energy in the rotor in the form of electrical energy when the motor returns and when the speed of the rotor decreases. These systems store mechanical energy in the form of kinetic energy. They have an electrical input to accelerate the rotor to the speed used by the motor. Then, the electric energy used by this engine is returned like a generator. These systems are designed in two ways, one is a rotating disk with an axis in its center and the other is a hollow cylinder controlled by magnetic bearings. The most reliable factor in the design of flywheels is the materials used in their edges. The rim of the flywheel must be made of materials with a high tensile strength coefficient in relation to their density in order to increase the kinetic energy stored in it. Therefore, the need for high tensile strength relative to density leads us to composite materials that have high tensile strength and low density, and the tensile strength relative to their density is 10 times that of steel.

Dynamic protection of the flywheel: The energy of a high-speed flywheel (up to 60,000 revolutions per minute) has great destructive power. The energy of one kilowatt-hour flywheel is capable of lifting an average-sized vehicle more than 100 feet vertically in the air. As a result, its rotating part must be locked in a protective case. 3 points that should be considered for the design of the flywheels in the hybrid vehicle are:

1. The possibility of breaking the rotor and hitting its housing during movement or due to an accident.

2. The gyroscopic effect of the flywheel can cause the vehicle to overturn when turning.

3. The shock caused by the road can affect the performance of the flywheel.

Electrical protection of the flywheel: Due to the high power required for flywheels in automatic mode, the required voltage is very high and usually around 300 to 500 volts. This high voltage may cause an electric shock to the driver, passengers and repairmen. To make a reliable flywheel, the effects of each of the other components of the vehicle and the characteristics of the system must be considered.

The engine and its controller: The electric motor and controller of the hybrid vehicle use electric energy to move the vehicle. In the serial type, an electric motor alone moves the wheels. In the parallel type, the combination of power units can drive the wheels through a power transmission system. In the series-parallel (Dual) system, the combination of both the above modes is used. That is, the controller controls the voltage and current reaching the motor. In a hybrid vehicle, the controller receives a signal from the gas pedal and controls the generation of electric energy for the engine, which produces the torque needed to turn the wheels.

There are two main groups of electric drive systems, which are: alternating current (AC) and direct current (DC). DC motors are generally easier to control, but are slightly more expensive. These engines are usually bigger and heavier. Most hybrid vehicles use AC motors because most of them have higher efficiency and a larger working range. When the internal combustion engine is used to provide the primary energy source, a microprocessor that receives signals from different parts of the vehicle, according to the charging status of the batteries as well as the movement status and the signal it receives from the gas pedal, using electronic control systems. Used in the vehicle, it adjusts the operation of the power transmission system and the combustion engine in such a way that the engine works in a mode that has the best possible fuel efficiency and provides the required output torque and speed. Of course, it is easier to do this in series than in parallel.

Power transmission system: In a normal vehicle, the combustion engine converts fuel into energy, but in a hybrid vehicle, other fuel conversion technologies are used. In normal engines, fuel is converted into mechanical rotational energy through combustion. In a hybrid vehicle, it is necessary to convert fuel energy into electrical energy to give the electric motor the ability to produce power. Since the goal in HEVs is to obtain maximum fuel efficiency, 3 types of engines are often used:

1. Gasoline engines that use direct fuel injection technologies. This type is used for light HEVs (personal vehicles).

2. Diesel engines, which are often used for heavy HEVs, such as buses, etc.

3. Gas engines that can only be used in series type HEVs. In these vehicles, it is very common to use new energy sources such as fuel cells or solar cells.

Body and chassis: The body of HEVs does not have a different shape from ordinary gasoline vehicles, but when energy efficiency plays an important role in their design, good aerodynamics and light chassis will increase the vehicle's efficiency. The two important factors that affect the aerodynamics of vehicles are: the drag coefficient Cd and the surface of the image facing A. The product of these two factors is proportional to the aerodynamic drag force of the vehicle. Another rear force of the vehicle is the rolling rear force, which is proportional to the weight of the vehicle. The set of these forces is expressed as follows: Ftotal = Froll + Faero Low fuel consumption efficiency and high engine performance and the possibility of weight reduction promise promising results in the design of hybrid vehicles. The reduction of environmental pollution and the reduction of fossil fuel consumption will open a new chapter in the design of future vehicles.

Electric hybrid vehicles are divided into three general categories: series, parallel, and series-parallel hybrid arrangements, which are shown in Figure (1). In a series hybrid vehicle, the degree of hybridization (combustion engine power to electric engine power equal to 100% or one, meaning that the power of both combustion and electric engines must be equal to each other. Therefore, the weight of the vehicle increases significantly compared to its power. As a result, the vehicle is used less in hybrid vehicles in a parallel hybrid vehicle, two electric and combustion engines are used in different modes for driving the vehicle. This type of vehicle also has different types in terms of compatibility with combustion vehicles without major changes in the combustion vehicle platform, it can be converted into an electric hybrid vehicle. In terms of the location of the electric and combustion parts, they are classified into two types: coaxial and non-coaxial hybrid systems combustors are placed on a common axis. Non-coaxial parallel hybrid systems are also divided into three categories with a combiner before the gearbox, with a combiner after the gearbox and independent parallel arrangement [4].

Almost most types of parallel arrangements require the design of a suitable gearbox and transmission system, and therefore, according to the time constraints and the cost of construction of this project, the independent parallel arrangement or TTR was selected. In this arrangement, a parallel hybrid vehicle can be made from an existing combustion vehicle with the least changes in the mechanical system of the combustion engine. Among the advantages of the independent arrangement are energy return in regenerative braking, higher efficiency compared to the series system, the possibility of using existing platforms and less complexity of construction. On the other hand, the impossibility of charging the batteries while the vehicle is stopped, the limitation in the working area of the electric motor due to the use of a constant speed gearbox on the rear axle is one of the disadvantages of this design.

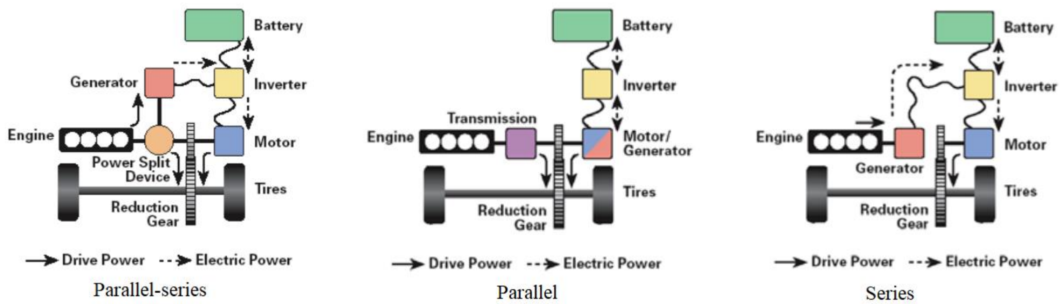

Figure (1) various configuration of HEVs

3. Results

One of the important reasons for simulating fuel consumption and pollutant production is to compare the results of vehicle performance with global standards, the use of simulation software helps a lot in reducing test costs. ADVISOR software is used in the simulation of hybrid vehicles and buses [3] and a project in the field of comparing the results of the simulation by the software and the results of the laboratory was vehicleried out by Mr. Randall Domm Senger in 1998 at the University of Virginia [4] and the results have been published [3]. This software is very accurate in simulating the vehicle and the results obtained from it correspond with the laboratory results with high accuracy.

3.1 The simulation by ADVISOR

In the ADVISOR software, on the input page, the user creates the desired machine model. There is a drop-down menu to select the machine setting. There are maps related to the functional characteristics at the bottom right, in the front part is a sphere for selecting scalar quantities. And they can be edited, and all the settings can be saved for the future. By clicking on the Continue button, we go to the page related to the simulation settings.

On the simulation page, the user defines the events to be simulated. Some of these cases include single driving cycle and combined cycle and special test layer. Also, in the right part of the window, the user selects the cycle and defines the simulation parameters. In the left part, the user can see the driving cycle diagram and the statistical analysis diagram, and when the simulation settings are done, click on the button. Run, the simulation is done and the results page appears at the end of the work. On the page related to the results, there is the ability to view the performance of the machine in the entire cycle or at any point of the cycle. In the right part, there is a summary of the results including fuel consumption and pollution. On the left side, the time dependent details are displayed, the results displayed on the left side can be changed to display other features such as engine speed, engine torque, and battery voltage.

As you can see in Figure (2), the data of the components are stored in the software in the form of a text file, and based on the user's choice, the appropriate data is loaded into the software.

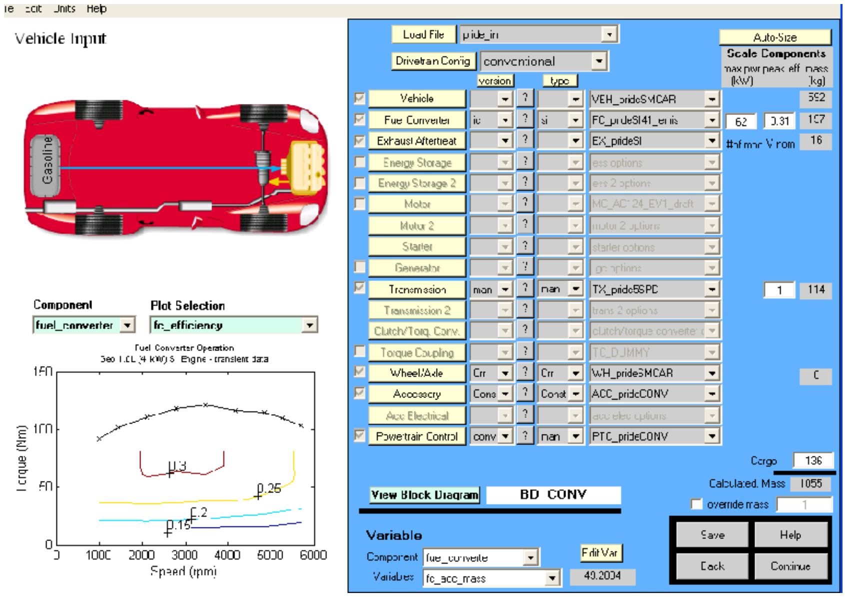

Figure (2) first page of ADVISOR software

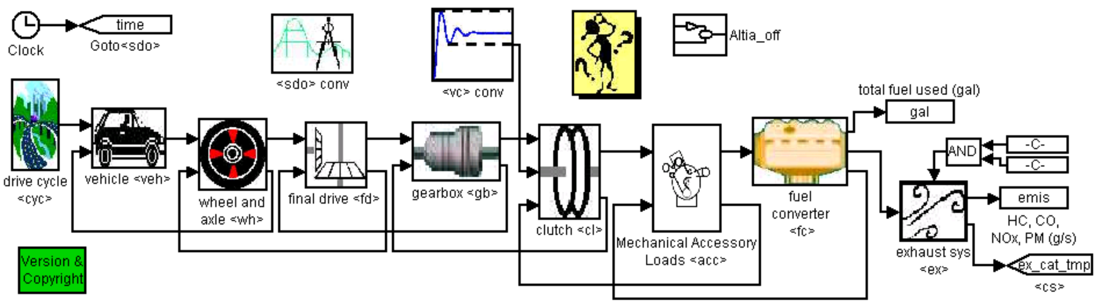

Figure (3) blocks of vehicle components that are connected to each other.

Finally, a real model is a combination of component models. A machine model is made from the combination of component models and then they are connected to each other to define the flow of torque, speed and power from one component to another. As mentioned before, ADVISOR software uses a backward/forward combination method for vehicle modeling, which is closer to the backward method. The difference between this method and the backward method is in the application of functional limitations of the components and the use of simple forward calculations. There are two main assumptions to justify the combination of backward and forward methods in ADVISOR software. These assumptions are given below:

1) None of the components of the power chain needs more torque or power than the torque or power consumption of its upstream component.

2) The efficiency of a component in forward calculations is equal to the calculated efficiency of the same component in backward calculations.

In the figure above, the block on the left, which is named motion cycle, is the point where the required speed is entered into the simulation in terms of time. The driving cycle block transfers the required speed to the vehicle body block. There is no performance limitation in the vehicle block. In this block, using the required speed, the average thrust force and the required average speed during the time interval are calculated. The requirements are sent from the vehicle block to the wheel/axle block. In the wheel/axle block, the force and linear speed are converted into torque and rotational speed. In this block, the effects of tire slippage, axle and wheel bearing resistance force, and wheel and axle rotational inertia are considered. The tire slip model, the weight on the tire, the weight on the tire, the longitudinal thrust force, the speed of the vehicle and the slip, is defined by the following equation.

$$slip = \omega_{wh,req} \times r_{wh} / v_{req} - 1 \quad (1)$$

Tire slippage is allowed up to a maximum amount and this limits the thrust force. The requested speed is also limited based on the maximum acceleration resulting from the thrust force. Advisor solves the following equations together to determine the maximum force and acceleration.

$$F = F_{traction}(dv/dt) - F_{aero}(v) - F_{rolling}(v) - F_{climbing} \quad (2)$$

As can be seen in figure (4), the required thrust force for the route reaches its maximum value of 2.1*4^10 when the step speed is requested. As the vehicle accelerates, the required power decreases. The maximum force that the tires can transmit is about 1.2*4^10.

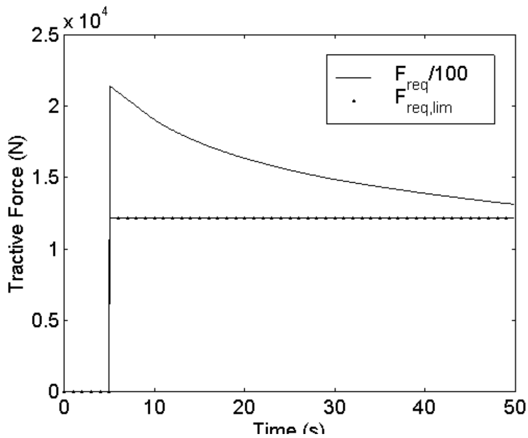

Figure (4) Freq of the requested force and Freq,lim of the limited requested force

Different requested speeds of the vehicle are shown in figure (5). The desired output speed of the driving cycle is indicated by Vtrace. The average requested speed during the time interval, which is the output of the vehicle block, is denoted by Vreq. The effect of the sliding model can be seen by comparing Vlim, req and Vreq. Vlimreq is the maximum possible speed of the vehicle due to the limitations of tire drift. Finally, Vact is the actual speed of the vehicle. It should be noted that in this example, the actual speed of the vehicle is lower than the Vlimreq speed due to functional limitations of the above components.

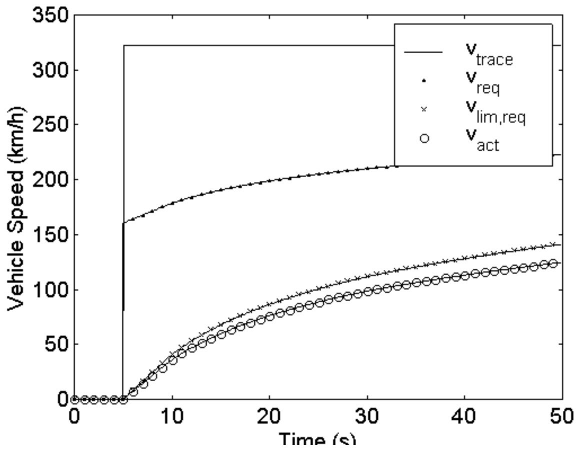

Figure (5) Vtrace is the speed required to pass the route, Vreq is the requested speed, Vlim is the limited requested speed, and Vact is the actual speed traveled by the vehicle.

The rotational speed required from the wheel is obtained from the tire slip model.

$$\omega_{wh,req} = (1 + slip) v_{lim,req} / r_{wh} \cdot \quad (3)$$

The required input torque to the axle is obtained by summing the torque needed to create average thrust, the momentum needed to drive the vehicle, and the momentum needed to accelerate the powertrain system.

$$\tau_{wh,req} = F_{lim,req} r_{wh} + \tau_{wh,loss} + J_{wh} \left(\frac{\Delta \omega_{wh,req}}{\Delta t} \right) \quad (4)$$

The wheel/axle block transmits the torque and speed requirements to the differential block. There is no performance limitation in this block and the required torque and speed are changed according to the gear ratio and torque loss. The next block is the gearbox, which also has no performance restrictions. After converting the torque and speed, the gearbox sends them to the engine/controller block. In this block, several performance constraints are considered. The block diagram of the motor/controller model is shown in figure (6). The upper half of this part is backwards simulation. The required output torque and speed are the inputs of the model and the power required to produce them is the output of the model. In the backward part of the model, three functional constraints are considered. The maximum requested speed is the maximum allowed speed of the engine. The maximum required torque is equal to the torque difference at the maximum velocity and the momentum needed to initiate the rotation of powertrain components.

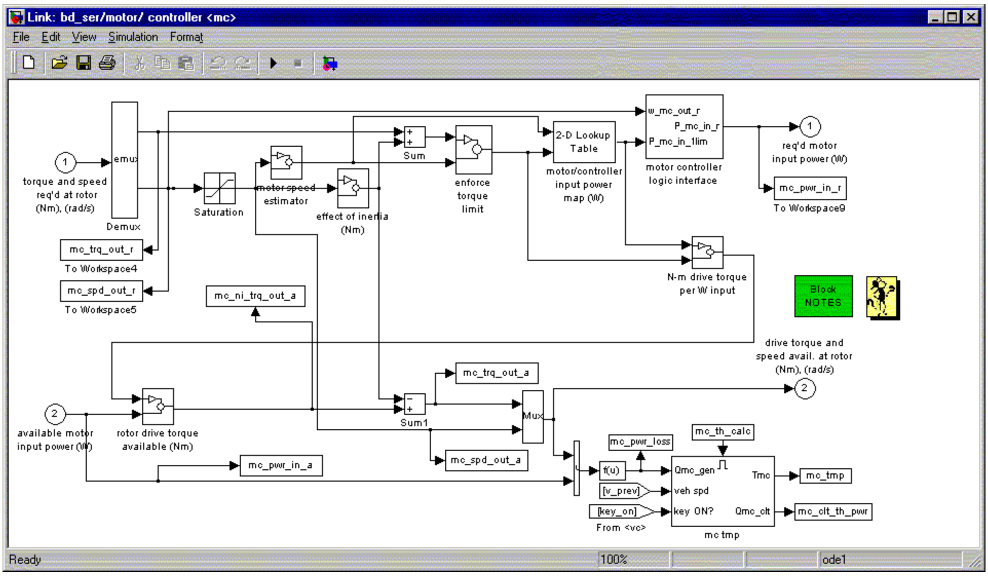

Figure (6) block diagram of electric motor/controller

The limited torques and speeds, together with the engine map, are used to calculate the required electric power. Finally, the motor power is limited by the maximum current of the motor controller. These constraints are explained by the following equations.

$$P_{mot,in,req} = \min\left(P_{mot,in,map}, I_{con,max} V_{bus,prev}\right)$$

$$P_{mot,in,map} = f\left(T_{mot,lim,req}, \omega_{mot,lim,req}\right)$$

$$\omega_{mot,lim,req} = \min\left(\omega_{mot,req}, \omega_{mot,max}\right)$$

$$T_{mot,lim,req} = \min\left(f_1\left(\omega_{mot,lim,req}\right), T_{mot,req} + J_{mot}\left(\frac{\Delta\omega_{mot,lim,req}}{\Delta t}\right)\right) \quad (5)$$

F1 is a relationship that expresses the torque curve of the engine. When the vehicle speed in the previous time interval is more than 1.6 km/h less than the requested speed, Wmot, lim, req are replaced by the actual engine speed in the previous time interval in the above equations. This value is estimated with the following equation.

$$\omega_{mot,act,prev} = \left(v_{act}\left(\frac{\omega_{mot,lim,req}}{v_{avail}}\right)\right)_{prev} \quad (6)$$

The effect of the equation can be seen in figure (7). In the example of acceleration evaluation, after 5 seconds, the engine torque production request is more than the maximum allowed torque. From this time onwards, maximum torque is used to obtain the input power to the engine. The effect of the equation can be seen in figure (8). Approximately after 42 seconds of engine speed demand, it is allowed to exceed the maximum speed. From now on, the maximum speed is used to get the input power to the engine.

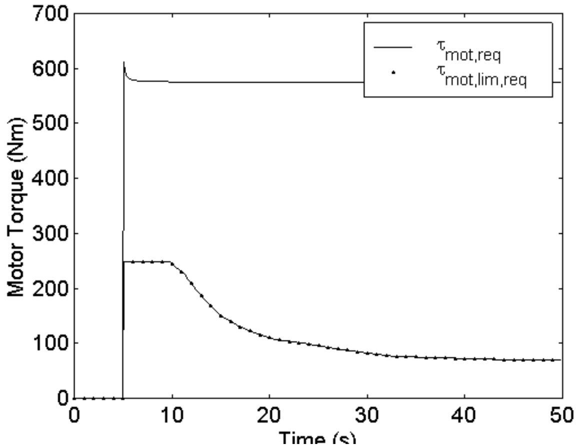

Figure (7) mot, reqτ requested torque from the motor and mot, lim, reqτ requested torque according to the limitations of the electric motor

Pmot,in,map is the input power required by the engine to produce torque and speed is limited. Pmot,in,req is the power that the engine requests from the power bus and the batteries or the generator must produce it.

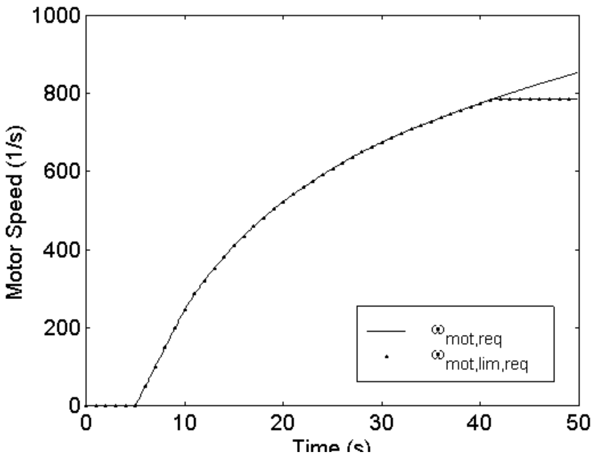

Figure (8) Wmot,req required rotational speed of gearbox and Wmot,lim,req rotational speed limited by electric motor

For the example of acceleration, it can be seen in Figure (9) that between 9 and 28 seconds, the engine needs more power than its maximum power, which is determined based on the maximum current of the controller, to produce torque and limited speed.

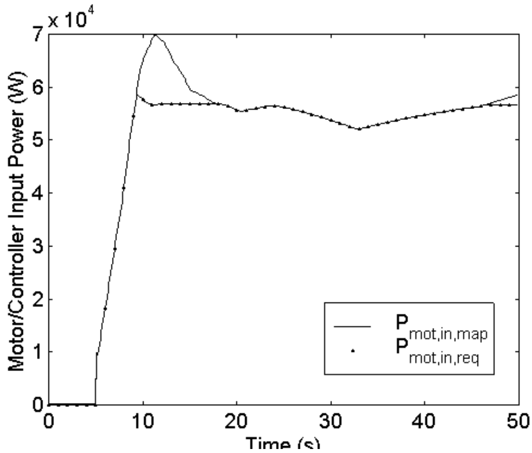

Figure (9) Pmot,in,map required power of the electric motor measured by map and Pmot,in,req the power that can be provided for the motor

3.2 The effect of the driving cycle on the amount of vehicle pollution:

To simulate the sized vehicle, and compare its performance with the baseline, the standard driving cycle Cyc_UDDS as shown in Figure 10 is considered as the system input. Also the properties of the mean, maximum speed and acceleration and also time and distance of the Cyc_UDDS are presented in table 1.

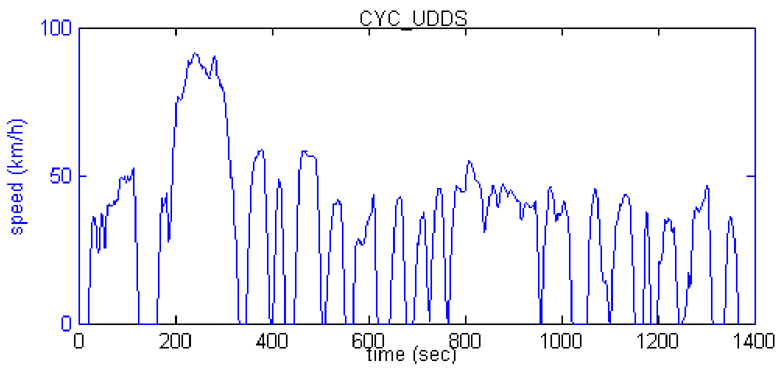

Figure (10) UDDS cycle

Table (1) specifications of UDDS cycle

Time(s(	Distance(Km(	Max speed (Km/h(	Avg speed)Km/h(	Max accel)m/s^2(	Avg accel)m/s^2(	Max decal)m/s^2(	Avg decal)m/s^2(	Idle time)s(	No. of stops
1369	12	91.25	31.51	1.48	0.5	1.48-	0.58-	259	17

By simulating the system in two modes and comparing the results for vehicle performance, fuel consumption and emissions, it can be seen that (table 2) with proper vehicle sizing, fuel consumption and emissions can be reduced by 10 and 12 percent, respectively, while maintaining the dynamic and performance characteristics of the vehicle.

Table (2) values of fuel consumption and pollutant production with UDDS cycle

Vehicle	Hc (g/Km)	Co (g/Km)	Nox (g/Km)	Pm (g/Km)	L100 (L/100Km)	Gasoline eq. (L/100Km)	Distance (Km)
Sized power-train	0.365	1.564	0.258	0	4.9	5.4	12
conventional_defults_in	0.398	1.622	0.262	0	5.3	5.8	12

4. Conclusion

One of the most important issues in the world of science today in order to clean the environment as much as possible from the damage of fossil fuels is the use of emerging computing methods to optimize the design of hybrid vehicles as much as possible. By using these methods, it is possible to optimize the design parameters and take steps towards reducing environmental pollution and using less fossil fuels. In the recent research, first, a brief introduction about the optimization algorithms used in this research will be presented, then the optimization problem will be defined including obtaining cost functions and design parameters, then using optimization methods in order to optimize It comes between two opposite characteristics related to the power transmission system of hybrid vehicles, i.e. fuel cost and vehicle performance. Due to the proper use of the electric motor and battery in order to reduce fuel consumption, the battery and motor resistance losses in the optimized power transmission system are lower than the base case. Also, the efficiency of the fuel converter and electric motor systems will also improve.

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