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Emissions and fuel economy for a hybrid vehicle

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HIGHLIGHTS

- The simulation code developed can be used a research or design tool for the evaluation of mixed hybrid electric vehicles.
- All mixed hybrid vehicles are more economical than the conventional vehicles although they produce almost the same power.
- CO_2 emission is theoretically reduced nearly 30% by mixed hybrid electrical vehicles.

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ABSTRACT

Conventional vehicles play a big role in city transportation all over the world. These vehicles run on energy obtained from fossils fuels such as petroleum oils that pollute environment with the gases that are emitted after burning. In addition, the cost of this fuel type will increase because of decreasing reserves; therefore, these petroleum oils must be used very efficiently. Due to environmental and financial problems, the development of clear and efficient city transportation has accelerated. Hence, hybrid electrical vehicles gain significant importance because they are environmentally friendly and efficient in fuel usage. In this study, a conventional commercial vehicle was chosen for design to a mixed hybrid systems. A simulation program was created for road simulation of these vehicles and with acceleration included; the consumption and emission values were also approximately calculated. As a result, it was seen that the mixed hybrid vehicles possess the same performance values with low fuel and CO_2 emission.

1. Introduction

With the increased interest in global environmental issues in recent years, the demands on technology to reduce automobile fuel consumption have further increased. Attention in the area of vehicle bodies is currently focused on reducing size and weight. In the area of the engines, efforts are underway to develop direct injection gasoline and diesel engine technologies to improve fuel efficiency. In the entire field of vehicle technology, hybrid systems are attracting attention, and some hybrid vehicles have already been released to the market [1]. A hybrid vehicle is a vehicle which uses two or more kinds of propulsion. Most hybrid vehicles use a conventional gasoline engine as well as an electric motor to provide power to the vehicle. An important characteristic of hybrid electrical vehicles is the influence of low ambient temperatures on fuel consumption and pollutant and CO_2 emissions [2]. The definite advantages of the hybrid electrical vehicles are to extend greatly the original electrical vehicle driving range by two to four times and to offer rapid refueling of liquid gasoline or diesel [3].

Nowadays some manufacturers produce new vehicles for using a hybrid system but some of the other manufacturers transform their current models into hybrid system. However, some problems have to be solved during transformation. One of the most important problems is the design of the controller. For the design of the controller, vehicle simulation must be done. Controller design could be changed according to the used engine type and battery type in the simulation. Vehicle characteristics can be seen in different compositions. The most efficient design can be created only by this method [4].

A search of the recent literature reveals that a number of computer software simulations are available specifically for hybrid electrical vehicles. These simulation tools have varying abilities to predict vehicle performance in one or more areas, such as fuel economy, emissions, acceleration, and grade sustainability. Some of the more prominent tools are Matlab/Simulink based The Advanced Vehicle Simulator (ADVISOR) [5], A Hybrid Vehicle Evaluation Code (HVEC) [6], CarSim [7], SIMPLEV [8], CSM HEV [9], Elph/V-Elph [10].

In this study, a simulation program was created for road simulation of the vehicles and using different amounts of traffic flow information are compared in terms of fuel economy and CO_2 emissions over common city and motorway drive cycles. In

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Nomenclature

n	engine speed (rpm)	BSFC(n)	specific fuel consumption
x	gear position	Ct	CO_2 emission, gr
g	gravity, 9.81 m/s^2	α	slope (°)
m	vehicle mass (kg)	V_w	wind speed, km/h
cw	coefficient of air friction	R_{wheel}	radius of wheel, m
A	front area of the vehicle (m^2)	C_{wheel}	circumference of wheel, m
ρ_a	air density, 1.2 kg/m^3	$V(n)$	velocity of vehicle, km/h
ρ_{ya}	density of fuel (kg/m^3)	$P(n)$	total power, HP
Df	differential gear	$T(n)$	total torque, Nm
gear(x)	gear ratio	$F_t(n)$	total force at wheels, N
D_{rim}	diameter of rim (inch)	$F_f(n)$	force of wheel friction, N
W_{wheel}	wideness of wheel (mm)	$F_a(n)$	force of air friction, N
t_{wheel}	thickness of wheel (mm)	$F_c(n)$	climbing force, N
$P_{\text{elec}}(n)$	power of electrical engine (HP)	$F_{\text{net}}(n)$	net force at wheels, N
$P_{\text{ice}}(n)$	power of ICE (HP)	$a(n)$	acceleration, m/s^2
$T_{\text{elec}}(n)$	torque of electrical engine (Nm)	th(n)	acceleration at a moment, m/s^2
$T_{\text{ice}}(n)$	torque of ICE (Nm)	FC(n)	fuel consumption at a moment, lt

order to develop a fair comparison between the technologies conventional vehicles and hybrid vehicles that matches the performance characteristics of the baseline intelligent vehicle is used. Furthermore, the values are compared with the conventional vehicle values. The flow chart of the simulation program is shown in Fig. 1. The road simulations show that the new designed mixed hybrid vehicles are as fast as conventional vehicles and mixed hybrid vehicles have low fuel and CO_2 emission values than conventional ones. Low volume internal combustion engine has an equal or better performance than the conventional vehicle and the electrical motor.

2. Hybrid electrical vehicles

In hybrid electrical vehicles, there are more than two energy sources. Mostly, one of them is electrical energy and the other is fossil energy. There exist three mainly types of hybrid systems in the market: series, parallel and mixed type. In series hybrid drive systems, there are no mechanical connections between the internal combustion engine and the wheels. First, all thermal energy is converted into mechanical energy in a thermal engine and then converted into electrical energy by a generator driven by the thermal engine. Additionally, there is an electric traction motor to drive the wheels. Hence a decoupling of energy source operation from the required traction power is possible. In most cases, the energy source, also called auxiliary power unit (APU), will act as base power unit delivering power to the battery or directly to the electric traction motor. The battery acts as peak power unit or energy buffer while driving. The series hybrid has the advantage of operating a thermal engine in a selected optimal operating field, for instance, with low specific fuel consumption in the torque-speed operating area but it must be equipped with big-size batter pack and generator [11].

In parallel hybrid drive systems, internal combustion engine and electrical engine are both connected to the wheels. The electrical engine may also be used as a generator to charge the battery by either regenerative braking or absorbing excess power from the internal combustion engine when its output is greater than that required to move the wheels [12]. One advantage of the parallel hybrid electrical vehicle over the series type is that parallel type requires a smaller internal combustion engine and electrical engine to provide similar performance, but the internal combustion engine works in variational cycles similar to the conventional vehicles; therefore, fuel consumption is higher than the series hybrid system [13].

Mixed hybrid system, shown in Fig. 2, has advantages and disadvantages of series and parallel hybrid systems. High efficiency can be obtained in a mixed hybrid vehicle, a concept that combines both the series and parallel systems. The internal combustion engine power can be used for both vehicle and electric alternator drives [14]. The advantage of this system is obtained from the optimized internal combustion engine operating strategy. Generally, operating the internal combustion engine under low load causes inevitably bad efficiencies, especially for gasoline engines. Such engine map areas can be avoided by increasing the load and resulting the power output. The excess power can be used for powering the electrical engine and charging the batteries [15].

3. Vehicle subsystems and models

For this purpose, two mixed hybrid conventional commercial vehicle models with identical electrical equipment but different internal combustion engines were designed. And they were compared with two conventional commercial vehicles. Conventional vehicles have five gear ratios but hybrid vehicles have three gear ratios because of their higher power. These vehicles parameters used in this study are listed in Table 1.

3.1. Vehicle main parameters

Radius of wheel, R_{wheel} described as follows:

$$R_{\text{wheel}} = \frac{2 \times \Pi}{100} \times \left(\frac{W_{\text{wheel}} \times t_{\text{wheel}}}{1000} + D_{\text{rim}} \times 1.27 \right) \quad (1)$$

where W_{wheel} is wideness of wheel, t_{wheel} is thickness of wheel, D_{rim} is diameter of rim. Then circumference of wheel C_{wheel} is can be evaluated by:

$$C_{\text{wheel}} = 2 \times \Pi \times R_{\text{wheel}} \quad (2)$$

Speed of the vehicle $V(n)$ can be evaluated by:

$$V(n) = \frac{3.6 \times n \times C_{\text{wheel}}}{60 \times Df \times \text{gear}(x)} \quad (3)$$

In this equation, Df is differential gear ratio, x is gear position and n is motor speed.