International Journal of Oil, Gas and Coal Engineering
2017; 5(4): 54-58
http://www.sciencepublishinggroup.com/j/ogce
doi: 10.11648/j.ogce.20170504.14
ISSN: 2376-7669(Print); ISSN: 2376-7677(Online)

Performance Investigation of a Series-Parallel Petrol-Electric Vehicle

C. C. Kwasi-Effah[1], A. I. Obanor[1], O. O. Ogbeide[2]

[1]Department of Mechanical Engineering, University of Benin, Benin City, Nigeria
[2]Department of Production Engineering, University of Benin, Benin City, Nigeria

Email address:
collinshicent@yahoo.com (C. C. Kwasi-Effah)

To cite this article:
C. C. Kwasi-Effah, A. I. Obanor, O. O. Ogbeide. Performance Investigation of a Series-Parallel Petrol-Electric Vehicle. *International Journal of Oil, Gas and Coal Engineering*. Vol. 5, No. 4, 2017, pp. 54-58. doi: 10.11648/j.ogce.20170504.14

Received: February 3, 2017; **Accepted**: March 3, 2017; **Published**: October 23, 2017

Abstract: The energy savings potential of a 1325kg series-parallel petrol-electric vehicle was evaluated using simulated high way fuel economy test (HWFET) and urban dynamometer driving schedule (UDDS) drive cycle data. Analysis showed that, the average percentage reduction in fuel compared to the most efficient conventional car is approximately 60% combining both cycles. This paper also shows that, the regenerative braking system recovers at least 1% of the energy loss associated with the internal combustion engine in every 1.789km distance of the UDDS drive cycle and 3.756km in the highway drive cycle when compared to the conventional braking system.

Keywords: Series-Parallel, Gasoline-Electric Vehicle, UDDS, HWFET, Internal Combustion Engine, Hybrid, Energy, Appraisal, Efficient, Regenerative Braking

1. Introduction

In recent years, the hybrid electric vehicle (HEV) has become of significant interest in vehicle design philosophy due to the global pressing environmental concerns and skyrocketing price of oil. The importance of addressing fuel efficiency in road transport is rising globally. Road transports are responsible for 17-18% of global CO_2 emissions from fossil fuel combustion [1]. Analysis of road transport growth has shown that car ownership will continue to increase as years pass by [2]. Hence, the emission rate of CO_2 will increase correspondingly. Presently, Nigeria has an average of six million conventional cars, constituting an average concentration of 25 ppm of CO and 0.6 ppm of NO_x which is approximately 25% - 30% in excess of the local standard recommended by the United Nations Environment Programme (UNEP) [3], thus, resulting in adverse health condition of road users especially in urban areas. However, purely electric vehicles are seen as a long-term solution to this problem as existing batteries cannot store enough energy to give a satisfying distance range. Hybrid powertrain are originally conceived as a way to compensate for the shortfall in battery technology, and are today the realistic alternative to exclusive combustion engine vehicles [4].

A hybrid electric vehicle uses two or more power sources, usually a combustion engine and an electric machine (petrol-electric vehicle). It combines the range advantage of a conventional vehicle with the environmental benefits of an electric vehicle. These vehicles with onboard energy storage devices and electric drives allows braking power to be recovered and ensures that the internal combustion engine operates only in the most efficient mode, thus improving fuel economy and reducing pollutants. The major factors of concern in the development of HEV's are as follows: (a). Emissions – Available HEV technology will decrease emissions of conventional air pollutants substantially. However, similar emission reductions can be achieved with, e.g. CNG (compressed natural gas) and clean diesel vehicles with advanced emission control technologies, the HEV combines both non-CO_2 and CO_2 reductions. (b). Energy - HEVs decreases energy consumption substantially compared to conventional vehicles used today. Research has shown that over the average, hybrid electric vehicle useful life time savings can considerably reduce the amount of fuel consumption [5]. (c). Life Cycle Cost – While HEVs are more expensive initially, the fuel savings are recouped based on mileage and driving conditions. Analysis has shown that the HEV life cycle cost, including the cost of purchase, fuel and maintenance costs, is, in most cases, less than owning a conventional vehicle. However, these calculations are strongly dependent on fuel prices and taxes [2]. The most common way of classifying the petrol-electric vehicle is by their drivetrain architecture. The most common architectures are series, parallel and series-parallel. However, a series-parallel powertrain brings in more degrees of freedom to vehicle engine operation with added system advantages [6]. Also, the current state of art employs the series-parallel configuration.

Hybrid cars have been on the market since 1997, but are still limited due to high manufacturing cost but, there have been a growing demand. HEVs are expected to be introduced on an increasing scale in the next 5 to 10 years beginning from 2012 through enabling policies governing the transport sector (i.e. policies in line with environmental and energy factors) [7]. Carla and Tiago evaluated the energy consumption, emissions, and costs of plug-in hybrid vehicles (PHEVs) to be a factor of powertrain management, charging frequency, driving cycle and energy source [8]. While this hybrid technology is still maturing, a number of HEVs on the road can start making a significant change in transport energy usage today, and can help countries meet fuel efficiency targets by 2050.

This paper aims to shows the feasibility of the series-parallel petrol-electric vehicle in terms of its emission and energy reduction capabilities when used in Nigeria

2. Methodology

MATLAB/Simulink was used to model the Petrol-Electric Vehicle. The simulated model is based on the Toyota Prius series-parallel hybrid electric vehicle with the following component specification**:**

(a) The Electrical Subsystem is composed of four parts: The electrical motor, the generator, the battery, and the DC/DC converter. The electrical motor is a 500 Vdc, 50 kW interior Permanent Magnet Synchronous Machine (PMSM). The generator is a 500 Vdc, 30 kW PMSM. The battery is a 6.5 Ah, 200 Vdc, 21 kW Nickel-Metal- Hydride battery. The DC/DC converter (boost type) is voltage-regulated. (b) The power split device: It uses a planetary device, which transmits the mechanical motive force from the engine, the motor and the generator by allocating and combining them. It has a gear ratio of 2.6 revolutions. (c)The internal combustion engine subsystem: This is a 4 cylinder 1.5litre gasoline engine capable of producing a maximum power of 57 kW at 6000 rpm.

3. Results and Discussion

Figures 1 and 2 shows the simulated HWFET and UDDS drive

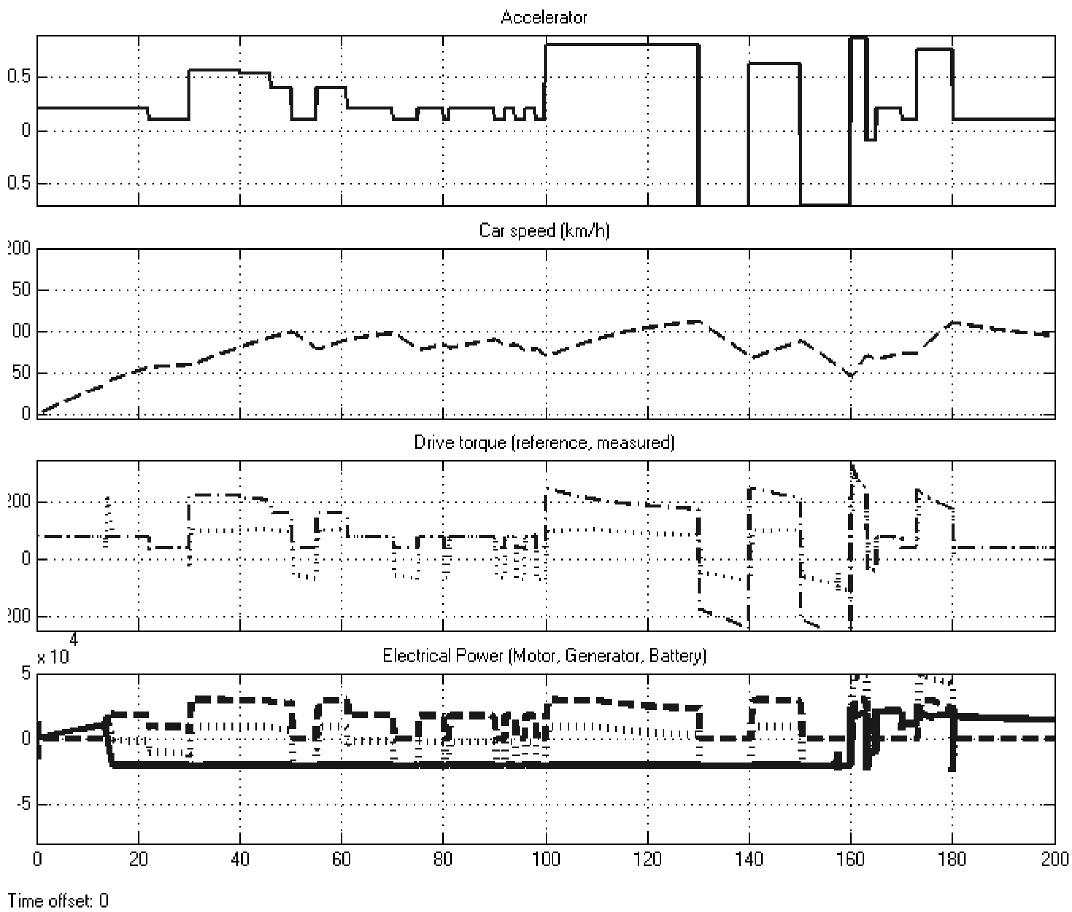

Figure 1. *HWFET drive cycle.*

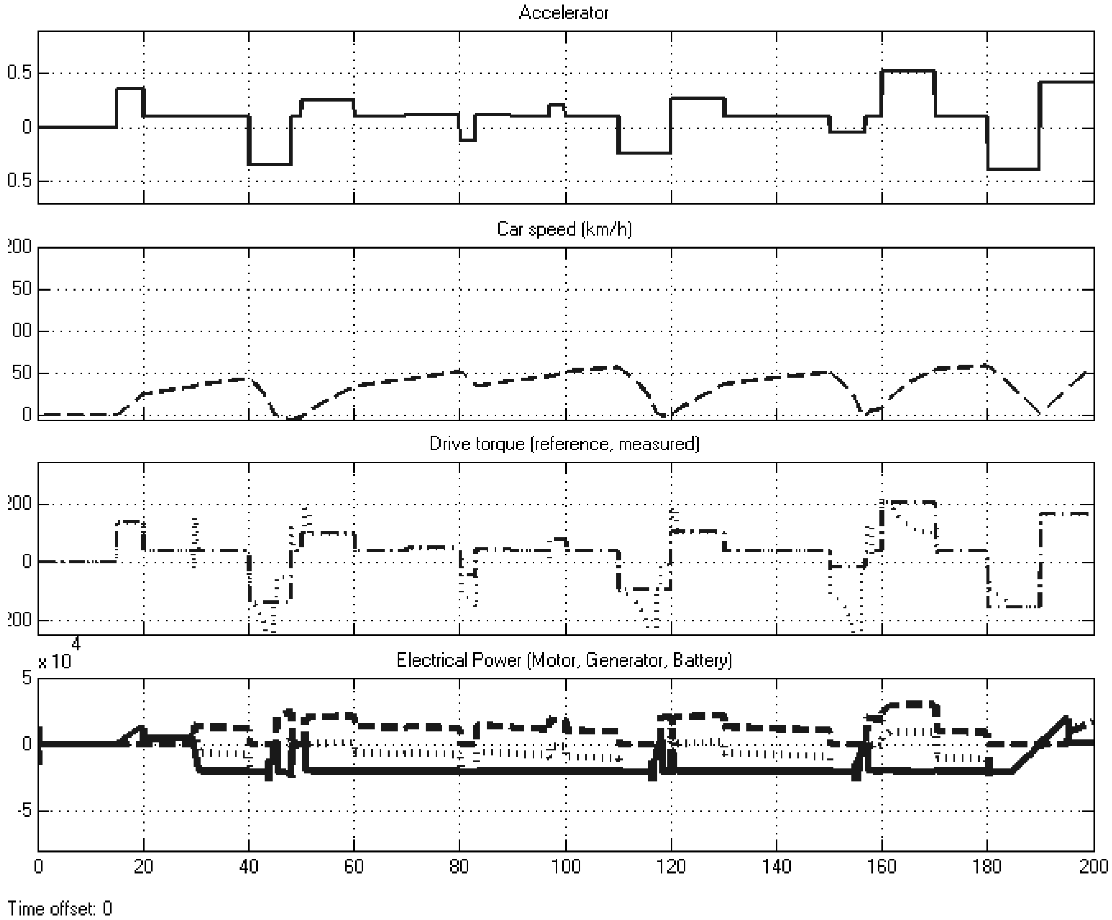

Figure 2. *UDDS drive cycle.*

Evaluation of Fuel Consumption

Given a torque demand from the driver, it will take a certain amount of fuel to develop that torque at a given vehicle speed. The amount of fuel required to develop that torque depends on the engine's efficiency at that torque and speed. So, if the value of torque, speed, and efficiency of the engine is known at that operating condition, then the fuel consumed at that point can be found through the mechanical power of the ICE. The difference between the brake power and the indicated power is the friction power. The instantaneous fuel energy input can be determined as follows:

$$\eta = P_S / Fi \tag{1}$$

Thus, from Equation 1, fuel energy input is given by:

$$Fi = P_S / \eta \tag{2}$$

In this analysis, we assume that the car consumes approximately 8.1 liters per 100 km of fuel (High way drive) and 11.1 liters per 100 km of fuel for city drive.

Due to memory constraints in simulation, the maximum time reference is limited to 200 s. This is an incomplete time reference in the real time drive cycle. However, assume that 0s to 200 s will remain steady over a 100 km for a complete HWFET and UDDS drive cycle.

From the simulated HWFET plot, average speed = 67.6 km/hr

Distance covered = 67.6 km/hr x 200/3600 hr = 3.756 km

The higher heating value (HHV) of gasoline (premium motor spirit) is 34.8MJ per litre [9]

From the simulated HWFET, Approximated total fuel energy input = 5,500 kJ

Hence fuel consumption = 5,500 e^3 /34.8 e^6 =0.14 litre per 3.756 km

Assuming driving pattern remains steady over a 100 km thus, the fuel consumption per 100 km = 0.16 x 100/3.756 =4.260 litre per 100 km

Therefore, percentage reduction in fuel consumption is approximately 49 %.

Energy recovery during regenerative braking is a function of the weight of the vehicle and its instantaneous velocity [10]. Thus the degree of regenerated energy is a function of the vehicle's instantaneous kinetic energy i.e $K.E=1/2MV^2$ and the efficiency of the capturing device e.g battery and ultra capacitors.

Mechanical braking was applied 3 times i.e at 130 s, 150 s and 162 s. The energy recovered can thus be calculated from these reference points.

At 130 s, Given:

Vehicle Speed before braking=110 km/hr =30.556 m/s

Vehicle Speed after braking=75 km/hr =20.833 m/s

Duration of braking= 10s

Vehicle mass = 1325 kg

Thus,

Instantaneous energy before braking = ½(1325x30.556^2) = 618.556 kJ

Instantaneous energy after braking =½(1325x20.833^2) =287.533 kJ

Recovery energy = 618.556-287.533=331.023 kJ

Required energy absorption rate (Power) = 331.023/10 =33.1023 kW

By comparing with the actual measurement from the plot, the total loss associated in generator, battery, motor shaft e.t.c is approximately 39 %.

Given:

Battery Capacity = 6.5 AH,

Generator input voltage to battery= 300V at point 130 s

Generator Input current to battery= 60 amps at point 130 s

From the simulated plot, since duration of braking is 10 s (i.e 130-140 s)

The percentage increase in SOC can be calculated as follows:

Battery capacity filled within 10 s of applied brake = 0.0027 hr x 60 Amps 0.162 AH

Thus,% Increase in SOC= 1 -(6.5-0.162)/6.5=2 %

Table 1 shows a summary of the total recoverable energy in a distance of 3.756 km

Table 1. *Recoverable energy (HWFET).*

Reference Point	Vehicle Speed (km/hr)		Duration of Braking (s)	Instantaneous Energy (kJ)		Recovery Energy(kJ)	% Increase in SOC
	Before	After		Before	After		
130	110	75	10	618.556	287.533	331.023	2
150	90	50	10	414.112	259.712	154.422	2
162	70	68	2	250.533	236.412	14.0912	1
Total						499.536	

If 3.756 km gives 499.536 kJ of energy recovered, thus, for continuous steady motion as assumed earlier, 100 km will give 13, 145.69 kJ Approximately This recoverable energy is thus useful for the hybrid system to maintain its characteristic advantage of its fuel savings potential.

Also, the average shaft power output of the ICE is 52 kW. Comparing this value with efficiency map, the average efficiency is approximately 20 %. Thus, the average power loss from the ICE is approximately 208 kW (i.e 260 kW-52 kW). The energy loss in 200 s approximately is 52,000 kJ.

Average loss in ICE with recovery in battery will be

52,000- Average battery recovered energy

=52,000 – 171 =51,829 kJ (Useful power output)

Therefore percentage of recovered lost energy by ICE is

=1-(51,829/52,000) =1% in every 3.756 km

Thus for a 100 km distance travel, percentage of recovered lost energy by ICE is

26.624 %

From UDDS, car average speed = 32.2 km/hr

Distance covered = 1.789 km

Approximated total fuel energy input = 1,938 kJ

Hence fuel consumption = 1,938e^3 /34.8e^6 =0.056 litre per 1.789 km

Fuel consumption per 100 km = 0.056 x 100/1.789 =3.130 litres per 100 km

Therefore, percentage reduction in fuel consumption compared to the most efficient conventional car is approximately 70.5%. Mechanical braking was applied 5 times i.e at 40 s, 80 s, 110 s, 150 s and 180 s. The energy recovered can thus be calculated from these points.

Table 2. *Recoverable energy (UDDS).*

Reference Point	Vehicle Speed (km/hr)		Duration of Braking (s)	Instantaneous Energy (kJ)		Recovery Energy(kJ)	% Increase in SOC
	Before	After		Before	After		
40	48	0	9	129.850	0	129.850	1
80	50	42	4	138.040	97.4	154.400	1
110	52	0	10	112.690	0	112.6900	2
150	50	0	7	138.040	0	138.040	1
180	55	0	10	167.030	0	167.030	1
Total						702.010	

Thus, for continuous steady motion as assumed earlier

100 km gives 41,294.71 kJ approximately

The average shaft power output of the ICE is 20 kW for the four cylinder engine. Comparing this value with the efficiency map, the average efficiency is approximately 20 %. Thus, the average power loss from the ICE is approximately 80 kW (i.e 100 kW-20 kW). The energy loss in 200 s approximately is 16,000 kJ.

Average loss in ICE with recovery in battery will be

=16,000 - Average battery recovered energy

=16,000 – 140.400 =15,859.600 kJ

Therefore percentage of recovered energy by ICE is

=1-(15,859.6/16,000) =1% for every 1.789 km and 55.897 per 100 km

From the simulated high way fuel economy test and urban dynamometer driving schedule drive cycle, within a

3.756km and 1.789km distance drive, the battery has so far been able to capture about 1% of the 80% average energy loss in the internal combustion engine. However, it is important to note that, this value will continue to vary increasingly as time elapses. Since the most efficient conventional car has a fuel consumption of about 8.1litre per 100km of the high way fuel economy test drive cycle and 11.1litre per 100km of the urban dynamometer driving schedule drive cycle, by comparing this with the fuel consumption of the gasoline electric vehicle, the percentage reduction in fuel consumption is approximately 70.50% and 49.00% of UDDS and HWFET drive cycle respectively. Thus, the average percentage reduction in fuel combining both cycles is 60%. The value of fuel savings and energy recovery of the regenerative braking system of the vehicle can be appreciated depending on the drivers driving pattern. According to [11], Plug-in hybrid electric vehicles (PHEVs) running on gasoline can reduce emissions by 20–60%, and fuel cell EVs can reduce GHGs by 30–50% when they run on natural gas-derived H_2 and up to 95% or more when the H_2 is produced and potentially compressed by using renewable feedstocks.

4. Conclusion

The energy recovery and fuel consumption of the petrol-electric vehicle has been evaluated using the UDDS and HWFET drive cycle data. The average percentage reduction in fuel of the GEV was found to be 60%. The energy loss due to low efficiency of the ICE has been compensated for by incorporating a regenerative braking system. This system has shown to make up for at least 1% of the energy loss in every 1.789km and 3.756km of drive in both city and highway cycle respectively.

Abbreviations

Ps = shaft output power, kW, T= torque, Nm, ω = angular speed, rev/min, η = efficiency, %, Fi =fuel input energy, kJ, e =exponential function, SOC= battery's state of charge, %

References

[1] Cacciola R. R and Sarva M. (2010). Adverse respiratory effects and allergic susceptibility in relation to particulate air pollution. Flirting with disaster. Vol. 1(2): 23-25.

[2] Rob d. J, Max A, and Elisa D. (2009). Overview of current technology and its application in developing and transitional countries. United Nations Environmental Programme (UNEP). Available at www. scholar.google.com.

[3] Utang P. B and Peterside K. S (2011). Spatio-temporal variations in urban vehicular emission in Port Harcourt city, Nigeria. *Ethiopian Journal of Environmental Studies and Management Vol. 4 (2): 37-51.*

[4] Yuliang L. Z (2005). Modeling and simulation of hybrid electric vehicles. Technical report, Department of mechanical engineering, University of Victoria.

[5] Maria G., James E. A. and Timothy J. W (2016) Cost-Effective Vehicle and Fuel Technology Choices in a Carbon-Constrained World: Insights from Global Energy Systems Modeling. Elsevier Electric and Hybrid Vehicles: 18-22.

[6] Wishart J. D and Dong Z. (2009). Modeling and simulation of two-mode hybrid vehicle architecture. 19th international conference on design theory and methodology USA.

[7] Ulrich E. and Rittmar H. (2010). Fuel Cell Electric Vehicles, Battery Electric Vehicles, and their Impact on Energy Storage Technologies: An Overview. Elsevier Electric and Hybrid Vehicles: 227-245.

[8] Timothy E. Lipman and Mark A. Delucchi (2010). Expected Greenhouse Gas Emission Reductions by Battery, Fuel Cell, and Plug-In Hybrid Electric Vehicles. Elsevier Electric and Hybrid Vehicles: 113-158.

[9] Don H. (2012). Extending value-added Ag marketing resource center and fuel economy. Available at www.extension.iastate.edu.

[10] Sandun K. (2010). Implementation and performance evaluation of a regenerative braking system M. eng thesis. College of Technology, Purdue University.

[11] Carla Silva and Tiago Farias (2010). Evaluation of Energy Consumption, Emissions, and Costs of Plug-in Hybrid Vehicles. Elsevier Electric and Hybrid Vehicles: 193-210.