Comparison of diesel and hybrid vehicle emissions by computer modelling

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Abstract

Regional passenger transport is a rapidly growing market in Europe, as a result of the need to minimise pollution in cities by reducing the demand for personal transport. Persistent requirements for mass transport include:

- Reduction in investment cost;
- Minimisation of emissions;
- Reduction of maintenance costs;
- Improvements in energy efficiency.

As the cost of electrification is often unacceptably high, diesel-powered vehicles are still the only remaining alternative. However, the maintenance costs associated with the diesel engine are very high, while frequent stop/start cycling on suburban routes results in high levels of noxious emissions and reduced energy efficiency.

This paper describes a hybrid power train simulation model, in which an electric vehicle’s operational performance has been set up to generate input data to a hybrid and a diesel vehicle model. Those models behave as independent vehicles predicting fuel consumption and emissions to be compared to each other running in identical traffic conditions.
1 Introduction

A realistic scenario between 2000 and 2005 has been drawn by government authorities and environmental protection agencies in order to reduce emissions in urban centres because of the risk to human health and the need to preserve global and urban environment\(^{(1)}\).

The vehicle industry is therefore mobilising effort and resources to reach environmental parameters established by Europe and the USA in order to help meet CO\(_2\) reduction target\(^{(2,3)}\).

Programmes have been sponsored by government funds with the objective to measure and analyse the effects of new fuel properties and vehicle technology on the exhaust emissions from gasoline, light-duty diesel and heavy-duty diesel vehicles. As a result of this effort, to accelerate the emissions reductions overall, Europe and the USA (since the early 1990’s) have introduced emission standards now accepted world-wide\(^{(4)}\).

2 Ultra low emission vehicles

Recently a new concept of vehicles has been researched and hybrid electric vehicles (HEVs) have been gradually introduced into the world market to achieve those emissions standards, for private and public transport\(^{(5)}\).

These types of vehicle do not need overhead wires making them flexible and autonomous due to the fact that they generate their own energy. HEVs are provided with a gas turbine, fuel cell or diesel engine big enough to drive a generator and an energy storage system, which can be a battery, flywheel or ultracapacitor to provide energy to the electric traction motors\(^{(6)}\).

3 Vehicle simulation

A simulation model has been developed in order to predict and compare the performance of a conventional diesel vehicle to that of a hybrid electric one operating on identical duty cycle. The hybrid electric vehicle model is shown in figure 1.

Matlab using Simulink\(^{(7)}\) tools have been used to model the vehicle and its components allowing accurate analysis of results. Simulink is a program that runs as a companion to Matlab. Simulink and Matlab form a package for modelling dynamic systems. Simulink provides a graphical user interface that is used in building block diagrams, performing simulations, as well as analysing results. Results are displayed by numeric oscilloscope or output on the Matlab work environment. It is also possible to integrate a Matlab program inside a Simulink model to use the wide range of functions this provides.
The flexibility in the design of hybrid vehicles comes from the ability of the controller to manage how much power is flowing to or from each component. In this way, the components can be integrated in accordance with a control strategy to achieve the optimal design for a given set of design constraints\(^8\). There are many, often conflicting, objectives desirable for HEVs, the primary ones being:

- To minimise fuel consumption
- To minimise emissions
- To minimise propulsion system life cycle costs
- To improve performance.

The model is designed to be as generic as possible, and can be adapted to any kind of configuration of motor, engine or storage energy unit, and any type of vehicle, road or rail.
4 Simulation of driver operation

Once the vehicle drive cycle has been specified, including distance to be covered, the driver action can be modelled by means of a driver subsystem model, shown in figure 3, which sets the acceleration, maximum speed and the point where deceleration must begin. The driver model thus works as any human driver in a real system, checking speed and distance, and accelerating and decelerating as necessary. Inside the driver model there is a drive cycle subsystem, which has been created to update the demand distance database so that multiple drive cycle can be simulated. This also determines the stop-time during which passengers would get on and off the vehicle. At this point the demand distance for the next cycle is updated.

The drive cycle input data is generated by a VISSIM model(9), which simulates the stochastic aspects of traffic flow in real time including vehicle behaviour.
Thus, the choice of the area to simulate the hybrid and diesel vehicles is very critical because the result validity depends from this decision. The first requirement was to choose a busy lane in the city centre, which suffers from pollution. The Bristol City Transport Department has been contacted to obtain information related to pollution in the entire Bristol road network, taking into consideration that Bristol is one of the most polluted cities in the South West of England. VISSIM can thus be used to generate realistic urban drive cycles.

As an example a road including a bus lane in Bristol, UK, shown in figure 4, has been modelled. Buses, private cars and other vehicles subjected to a fixed sequence of traffic lights and bus stops could be simulated.

Figure 5 shows the generated drive cycle of a specific bus. Distance, speed and acceleration data are saved in a suitable file extension, which can be read in Matlab. The driver model (fig 6) is able to read speed and acceleration demands given by Vissim generating fuel consumption and emission in real time in a specific route in Bristol. The Simulink vehicle model can thus predict fuel consumption for the HEV and diesel vehicle under this driving condition.
5 Fuel consumption and emissions modelling

The model can also predict fuel consumption and emissions for the hybrid electric and equivalent diesel powered vehicle operating over the same duty cycle. The diesel vehicle was assumed to be powered by a conventional 150 kW diesel engine using a measured fuel consumption map based on engine speed and power shown in figure 7\(^{(10)}\).
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Before being filtered

![Before filtered chart](image)

After being filtered

![After filtered chart](image)

Figure 5: Vehicle performance data generated by VISSIM
Look-up tables to read speed and acceleration data

Figure 6: Modified drive model

Figure 7: Fuel consumption map

This map was obtained from static measurements on a 1.9 litres turbo diesel engine and scaled up as required. The model can also predict emissions of CO, NOx, HC and Particulates, in the same way, using emission maps obtained from the same source\(^{(10)}\).
The diesel engine model incorporated a conventional gearbox and automatic gear changing routine with assumed transmission efficiency of 85%. The hybrid vehicle PMU was assumed to be powered at constant level of 40 kW by an equivalent diesel engine operating at its optimum efficiency.

Figure 10 shows the fuel consumption and emissions with each vehicle running within a generic drive cycle.
8 Conclusions

A comparison between hybrid electric and a diesel vehicle has established that, assuming both vehicles are running on the same particular operational and route conditions, using the model described, predicts the following reductions in fuel consumption and emissions due to hybrid vehicle operation compared with diesel operation:

- 35.7% fuel savings
- 63% CO
- 15% NOx
- 36% HC
- 70% Particulate emissions.

These results indicate the potential environmental benefit of a change from diesel to hybrid propulsion in urban transport.

References

1. Emissions standards: Europe and USA for heavy-duty diesel truck and bus engines- http://www.dieselnet.com
10. Private Communication between UWE, Bristol and Imperial College London