

Different Hybrid Powertrain Solutions for European Diesel passenger cars

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ABSTRACT

Fuel consumption and NO_x emissions of different Diesel-Electric hybrid powertrains, equipping a mid-size European passenger car were evaluated in this paper through numerical simulation.

Different degrees of hybridizations, from micro to mild hybrids, and different architectures and power sources management strategies were taken into account, in order to obtain a preliminary assessment of the potentialities of a Diesel-Electric hybrid system for the European passenger car market.

Both regulated driving cycles, such as NEDC, and "real-world representative" driving cycles, such as Artemis cycles, were evaluated, in order to obtain not only an estimate of the impact of hybridization on type-approval CO₂ and NO_x emissions, but also an assessment of the impact of these technologies from the vehicle owner's perspective.

Finally, the effects of internal combustion engine downsizing was also considered.

INTRODUCTION

In a context of growing demand for sustainable transportation worldwide, different technical solutions for hybrid vehicles are nowadays investigated as effective ways to improve efficiency of the driveline and thus to reduce CO₂ emissions [1].

So far the strong presence of Diesels as preferred route to improve fuel economy has prevented a substantial diffusion of hybrids in the European passenger cars market [2].

Both Diesel and Hybrid technologies represent effective solutions to reduce fuel consumption and in view of more restrictive regulatory CO₂ taxation also the use of Diesel in hybrid architectures could

provide interesting technical options, as long as they result commercially viable.

As a matter of fact, the new CO₂ emission targets set by EC [3] (130 g/km over NEDC to be reached within 2012, and 95 g/km as a long term goal for 2020) are extremely demanding, especially for the long term target.

For an "average" European passenger car (compact size, about 1300 kg mass) the energy requested over NEDC can be estimated approximately equal to 0.4 MJ/km [4], that means that engine average efficiencies values around 32-33% will be required to reach the 95 g/km target, as shown in Fig. 1 (assuming a "pure powertrain" approach to the CO₂ target achievement, that is, without considering possible benefits coming from reduction in rolling resistance due to "green" tyres, aerodynamics improvements, vehicle body lightening, etc.).

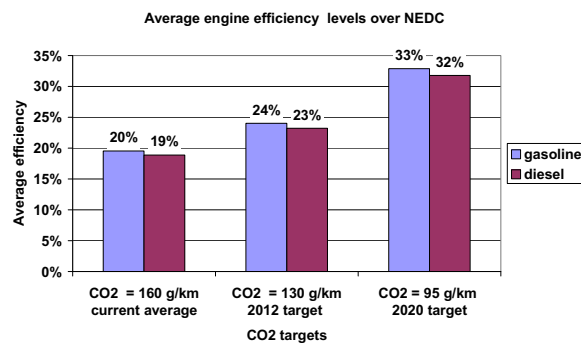


Fig. 1- Average efficiency levels over NEDC that must be attained to reach different CO₂ emission targets for gasoline and diesel engines.

However, over most of the NEDC the ICE is operated at low load, and thus with poor efficiency figures as shown in Figures 2 and 3, thus making the 95 g/km CO₂ target far beyond current system capabilities.

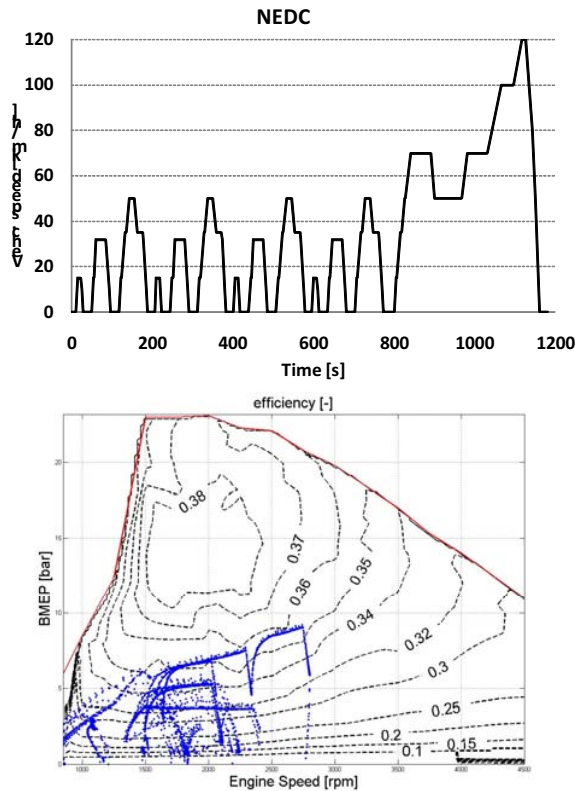


Fig. 2 - NEDC driving cycle: vehicle speed schedule (top) and corresponding engine operating points shown over the engine efficiency contour plot for a medium size European passenger car equipped with a conventional diesel powertrain (bottom).

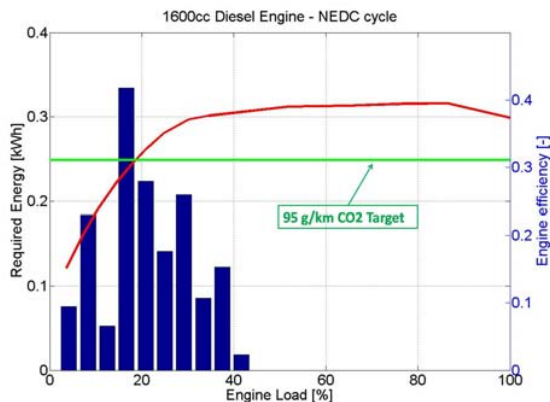


Fig. 3 - NEDC driving cycle: energy delivered by a conventional diesel powertrain grouped in engine load bins; typical engine efficiency vs. load trend also shown on right axis.

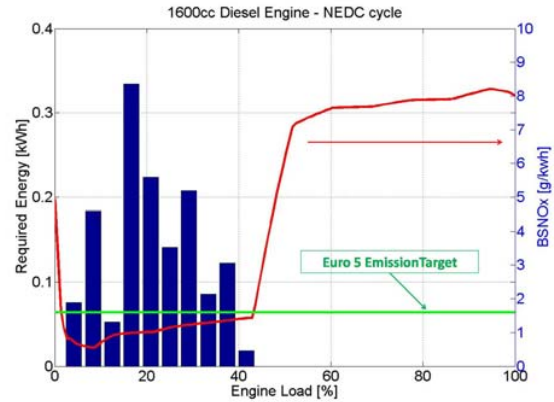


Fig. 4 - NEDC driving cycle: energy delivered by a conventional diesel powertrain grouped in engine load bins; typical brake specific NOx emissions vs. load trend also shown on right axis.

Therefore, it seems that a breakthrough from current technologies will be mandatory in order to achieve the future CO₂ targets, and coupling the high efficiency levels of diesel engines with the fuel saving potentials offered by hybridization could undoubtedly represent a valuable options.

However, despite these impressive potentialities, no Diesel Hybrid Electric passenger car models are already available on the market, neither in US nor in EU, and, although diesel propulsion systems could undoubtedly add further benefits to Hybrid Electric Vehicles (HEV) and could offer complementary advantages, such as for instance higher efficiencies in extra-urban driving conditions, the high values of efficiencies that can be already attained by conventional diesel vehicles may make more difficult the development of hybridization strategies enabling further improvements in a cost effective way [5]. Furthermore, some hybridization strategies aiming only to reach low fuel consumption targets may lead to unbearable penalties in terms of emissions, especially for NO_x, (as can be clearly seen in Fig. 4), and the add-up of the costs of hybrid and aftertreatment technologies which could be needed to meet future emissions regulations could seriously limit Diesel HEVs growth. Therefore, the trade-off between fuel consumption saving potential and the emissions constraints must be carefully considered in the hybrid strategy to avoid unexpected penalties in terms of emissions that could jeopardize Diesel HEVs advantages.

A careful analysis is therefore required in order to successfully develop Diesel HEVs, taking into account also possible peculiar issues that may hinder their widespread application.

Different degrees of hybridizations, from micro to mild hybrids, and different architectures and power sources management strategies were therefore

evaluated in this paper through numerical simulation for a mid-size European passenger car.

Both regulated driving cycles, such as NEDC, and “real-world representative” driving cycles, such as Artemis cycles (see Fig. 5 and 6 for examples and [6], [7] for more details), were considered, in order to obtain not only an estimate of the impact of hybridization on type-approval Fuel Consumption values (and thus on CO₂ emissions), but also an assessment of the impact of these technologies from the vehicle owner’s perspective.

Moreover, a particular attention was paid to NO_x emissions, because this pollutant undoubtedly represents the major barrier to diesel hybridization, since some fuel saving strategies may lead to increase in NO_x emissions that may mandatorily require the adoption of expensive aftertreatment devices.

Finally, the effects of internal combustion engine downsizing was also considered.

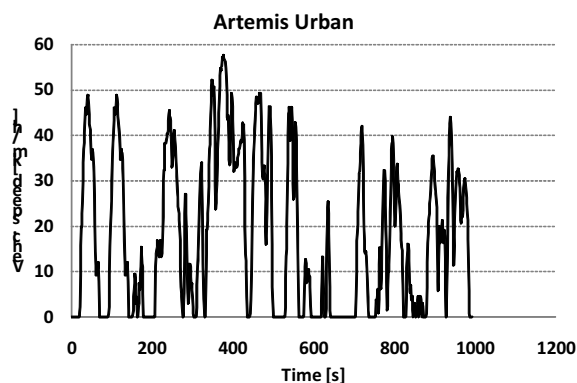


Fig. 5 - Artemis Urban driving cycle vehicle speed schedule.

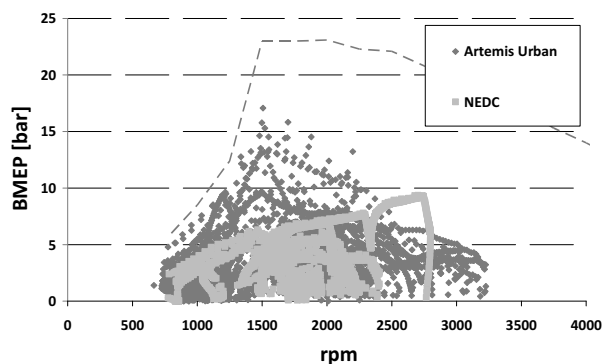


Fig. 6 - Engine operating points for a medium size passenger car equipped with a conventional diesel powertrain for NEDC (light grey) and Artemis Urban (dark grey).

HYBRID VEHICLE ARCHITECTURES

In this study, three different Front Wheel Drive (FWD) Hybrid Electric Vehicles (HEV) architectures equipped with a Diesel engine were compared and their performance in terms of Fuel Consumption (FC) reduction and NO_x emissions were evaluated through numerical simulations.

All the three different architectures are schematically shown in Fig. 7, along with the conventional diesel powertrain that was used as a reference, and their main characteristics are summarized in Table 1.

The first architecture “A”, which was used as a reference, is a medium size European passenger car, equipped with a Common Rail DI diesel engine (1.6 liter displacement) and a Manual Transmission (MT) gearbox.

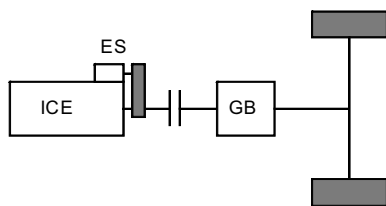
The second architecture “B” features a Belt Alternator Starter (BAS), i.e. an electric Motor Generator Unit (MGU) coupled to the Internal Combustion Engine (ICE) by means of a belt, that is capable of replacing the functionalities of both the starter and the alternator of the conventional architecture. Two different sizes of the BAS were considered: a low and a high power machine, with a rated power respectively equal to 2 and 10 kW. Depending on the size of the electric machine, different power management strategies may be enabled, as shown in following sections: in particular, with the low power machine, Stop&Start and high-efficiency electric generation are the only available functions, while with the high power machine also regenerative braking (although quite inefficiently, due to the unavoidable ICE motoring) and electric boosting (i.e. power assist during acceleration) can be performed.

The third architecture “C” features a Motor Generator Unit (MGU) installed between the ICE and the gearbox, which is usually referred to as Flywheel Alternator Starter (FAS). The two clutches allow the disconnection of the ICE from the FAS, in order to enable a more efficient regenerative braking and the pure electric drive mode. A 16 kW rated power MGU was selected for this architecture, corresponding to a mild level of hybridization, with a maximum electrical power available roughly equal to 18% of the maximum ICE power for the reference case with 1.6 liter ICE, and to 23% for the downsized 1.3 liter ICE.

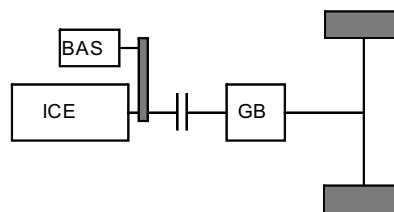
The fourth and last considered architecture “D” features the same Motor Generator Unit as architecture C, but coupled with a fixed transmission ratio to the output shaft of the gearbox. This architecture, although requiring a starter for the ICE, allows the same functionalities of architecture C, but may offer some advantages in terms of assembly

HEV MAIN COMPONENTS		
Vehicle	Type	FWD medium size passenger car
	Inertial Weight	1360 kg
	Road Load	13.9 kW @ 100 km/h
GearBox	Type	MT – 6 gears
ICE	Type	Common Rail DI Diesel
	Displacement	1.6 dm ³
	Rated Power	88 kW @ 4000 rpm
	Rated Torque	300 Nm @ 2000 rpm
ICE downsized	Displacement	1.3 dm ³
	Rated Power	70 kW @ 4000 rpm
	Rated Torque	225 Nm @ 1750 rpm
	Emission level	EU5
	Aftertreatment system	DOC + DPF
BAS Low Power	Rated Power	2 kW
BAS High Power	Rated Power [kW]	10 kW
Belt	Transmission ratio	2
MGU/FAS	Rated power	16 kW
	Transm. ratio (arch. D only)	12.5
Battery	Type	Li-Ion
	Energy	480 Wh
	Peak power	20 kW

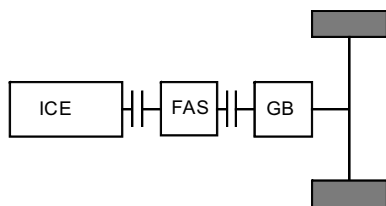
Table 1- Main Characteristics of the HEV components.



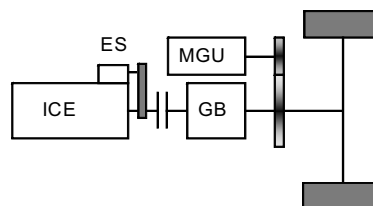
Architecture A (conventional vehicle)



Architecture B



Architecture C



Architecture D

Fig. 7 - Hybrid Electric Vehicles architectures (B, C and D) and reference conventional powertrain A