Energy Efficient Vehicles for Road Transport – EE-VERT

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Abstract

EE-VERT is a project funded under the Seventh Framework Programme of the European Commission concerned with improving the energy efficiency of road vehicles. In particular EE-VERT targets a 10% reduction in fuel consumption and CO_2 generation as measured on the standard NEDC. The central concept to EE-VERT is the deployment of an overall energy management strategy that coordinates energy demand and consumption by a network of smart generators and smart actuators. This paper describes the EE-VERT concept and the activities that will be undertaken to realise the project's goals.

1 Introduction

Road transport is the second largest producer of "greenhouse gases" within the European Union (EU) [1]. The European Commission has a declared strategy to reduce the overall production of greenhouse gases and in particular carbon dioxide (CO_2). Although overall greenhouse gas emissions in the EU fell by 5% over the period 1990–2004, the emissions of CO_2 from road transport rose by 26% in the same period. While improvements in vehicle technology have led to reductions in CO_2 emissions, for example the average CO_2 emissions in new vehicles was 186 g km^{-1} in 1995 but 163 g km^{-1} in 2004; increases in traffic volumes and congestion have been responsible for the net growth in CO_2 emissions in the sector. Reducing the CO_2 generated by road transport is therefore a key aspect of the overall strategy to reduce the production of greenhouse gases. To this end binding targets have been set with the objective of reducing the average emissions of CO_2 from new passenger cars in the EU to 130 g km^{-1} in 2012.

Technologies such as those to be developed in the EE-VERT project are a key part of achieving these required improvements. In particular, the significant improvements to be delivered by the EE-VERT project are needed in order to make road transport and the vehicles used in road transport a net contributor to decreasing overall levels of CO_2 generation in Europe. As the volumes of road vehicles in service and the CO_2 they produce are significantly greater than other surface transport means, EE-VERT presents an opportunity to make a substantial impact at the European level.

1.1 Existing Approaches

The majority of research efforts for CO_2 reduction up to now have been focussed on novel powertrain developments (particularly hybrid concepts). A hybrid vehicle has a relatively high potential to reduce CO_2 emissions but it presently requires cost-intensive and drastic technical modifications. Besides the higher costs these technical modifications also lead to the mass of the vehicle being considerably increased. Due to higher vehicle prices and lower economic efficiency hybrid vehicles have penetrated the automotive market relatively slowly in Europe, where up to now Diesel-engined vehicles have been the choice of the consumer for more efficient vehicles. Hence, hybrid vehicles can provide only a slowly increasing effect for the reduction of CO_2 emissions in the medium term.

A further aspect concerns the concepts for energy generation and consumption in the vehicle, particularly for auxiliary systems. In general, the energy required for auxiliary systems (e.g. power steering, water pump) is generated and consumed continuously, regardless of demand. Similarly, the energy generation for the vehicle's electrical system operates continuously. Some technologies have been deployed to the market that partially address these inefficiencies, for example electric power-assisted steering (EPAS/EHPAS) and regenerative alternators [2]. Nevertheless, these technologies may be viewed as "islands" of improving energy efficiency, but an overall energy management strategy has yet to be deployed.

From the above discussion, it can be seen that there are still significant potentials for energy savings in vehicles with conventional powertrains. Addressing the unoptimised electrical generators and consumers of today's vehicles can have a high impact on CO_2 reduction within the next ten years, affecting improvements for the whole range (types and models) of road transport vehicles. These improvements will also benefit hybrid vehicles.

1.2 The EE-VERT Approach

The EE-VERT concept is to combine several different approaches to energy saving within an overall energy management concept. The approaches include:

- Greater efficiency in energy generation with a new concept for the electrical machine and an optimised operation strategy;
- Improved efficiency in energy consumption, through electrification of auxiliaries and the use of more efficient electrical machines such as brushless DC motors;
- Energy recovery from wasted energy such as the use of thermoelectric devices to recover waste energy from the exhaust system;
- Energy scavenging from unused sources of energy, for example the use of solar cells;
- The use of short-term and long-term energy storage for recovered energy. Examples of the former include ultracapacitors; and of the latter more efficient battery technologies.

Note that EE-VERT will not carry out research into areas such as ultracapacitors, battery technologies and thermoelectric generators that are already being developed in other research activities. However, EE-VERT will develop an overall energy management strategy that permits the efficient integration of these technologies into a vehicle equipped with smart energy generation and smart actuators.

Fig. 1 shows an estimate of the benefit of EE-VERT technologies in a passenger car, where total savings of around 10% in fuel consumption and CO_2 emissions can be realised in the New European Driving Cycle (NEDC) through a combination of higher efficiency and minimising the energy demand for vehicle operation (4%), and overall energy management making use of energy recovery from sources on-board the vehicle (4–6%). In addition further measures that are not measurable on the NEDC but which can give a benefit of up to 4% in real-life usage are predictive algorithms for energy optimised operation (2%) and the use of solar panels to generate energy (2%).

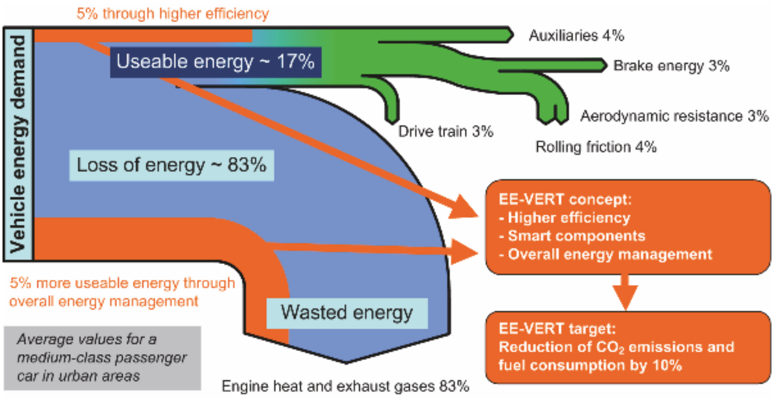

Fig. 1. Estimate of energy savings in a passenger car

2 EE-VERT Concepts

In this section further aspects of the concepts that will be developed in EE-VERT are described.

2.1 Electrical Architecture

The electrical system in conventional vehicles consists of a generator (the alternator) mechanically linked to the engine, an energy storage system (12V battery) and several consumers (loads) of which the power consumption can be actively controlled.

As discussed in the introduction, to increase the energy efficiency of the system, it is necessary to introduce new components able to recovery energy from other sources (e.g. kinetic energy recovery, exhaust gas thermo-electric recovery or solar cells) and place this recovered energy in short-term or long-term storage depending on the present and predicted demand from energy consumers.

It is possible to incorporate those energy recovery systems into the present-day electrical architecture. However, the simplicity of the electrical system severely limits the efficiency of energy recovery and energy management strategies that may be implemented. Firstly, there is a limitation on the maximum voltage allowed in the electrical distribution system. Since new power generation components with higher efficiency usually work at higher voltages, the efficiency of energy recovery systems is low. Secondly, energy management strategies are mainly limited to the control of power consumption of the loads.

Therefore, to permit integration of multiple generation, actuation and storage devices with different optimal operating voltages and usage profiles, a radical change in the electrical architecture is required. Consequently, it is necessary to divide the electrical distribution system into two parts: one electrical distribution system (14 V) for the existing auxiliary systems (such as lighting and radio) and a main electrical distribution system with a broader voltage range (14 V – 35 V) for efficient energy recovery. Both systems are connected by a DC/DC converter and incorporate different energy storage elements (ultracapacitors, high recharge batteries) according to the system and vehicle requirements. Fig. 2 shows a conceptual view of the proposed electrical architecture, with the two electrical distribution systems and the different elements in them: power generators, storage and consumers and the energy management and power control units (PCU) for control. This electrical architecture is scalable and permits the easy integration of additional elements such as solar cells to supply quiescent current demand as well as collecting energy during vehicle use.

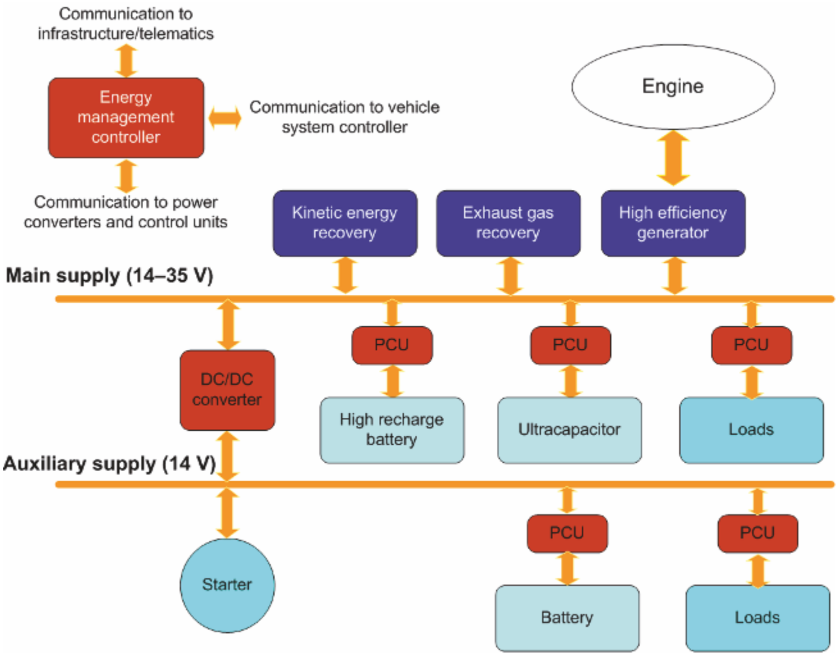

Fig. 2. EE-VERT electrical architecture concept

2.2 Power Generation

In the EE-VERT system electrical power generation is scheduled according to the demand from consumers. The improved EE-VERT generator will use a new type of electrical machine with higher efficiency at each operating point and optimised management of the generator operation. The operation management will lead to generator operation in regimes with a higher efficiency level.

The maximum efficiency of a state-of-the-art generator is 60 or 65%. However, the average efficiency is only about 40 or 45% in standard operation without operation management. Fig. 3 shows the operational area of a standard generator in comparison to the operation area of the proposed EE-VERT generator concept during the NEDC. Due to the low electrical power demand and the efficiency characteristics the average efficiency of a standard generator is only about 45% during the NEDC.

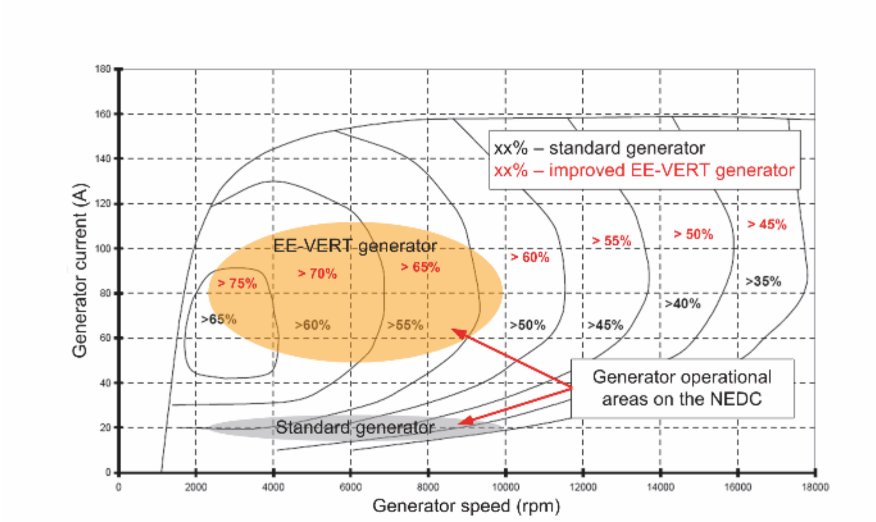

Fig. 3. Efficiency diagram for a standard generator

The efficiency for converting mechanical energy to electrical energy will be improved from on average 45% to on average 65% through novel design of the electrical machine and the operational strategy. Furthermore the electrification of auxiliaries will have a positive influence on the efficiency as well, due to a higher electrical power demand during the NEDC. The increased electrical power demand is compensated with considerable less mechanical power demand due to a demand-oriented operation of electrified auxiliaries.

The generator will also realise additional functionalities such as brake energy recuperation by a temporarily increased generator output power on a floating voltage level. Together with new energy storage devices this will lead to a further benefit for the reduction of fuel consumption.

Since a generator is necessary in every conventional vehicle, the generator therefore plays a key role within the EE-VERT system approach.

2.3 Overall Energy Management

In present-day vehicles, even in those regarded as the state-of-the-art, electrical power is generated with little knowledge of the actual loads, and some auxiliary systems consume power continually regardless of demand. In addition, increased electrification of auxiliary systems promises mass reduction and efficiency gains, but this can only be accomplished if the energy generation and distribution is continuously optimised and adapted to the current driving conditions and power demands.

In the EE-VERT system it is therefore envisaged that the electrical power generation will be scheduled according to the demand from consumers. Furthermore, energy can be recovered from other sources (e.g. regenerative braking, waste heat, solar cells) and placed in short-term or long-term storage depending on the present and predicted demand. This concept requires a radical change in the electrical architecture (as described in Section 2.1) to permit integration of multiple generation, actuation and storage devices with different optimal operating voltages and usage profiles. The EE-VERT system architecture will combine the contributions to energy saving possible from individual components and permit them to run optimally.

The architecture will deploy a distributed network of smart components, whose characteristics are co-ordinated to optimise their interaction and their efficiency. In addition to this, it is crucial to manage the use of different types of energy, such as electrical, mechanical or thermal energy, which means that an overall vehicle optimisation and management concept needs to be developed. Also, influence on energy consumption in the vehicle by the driver behaviour will be addressed, as will be the possibilities to extend the number of energy generating and harvesting devices.

A further aspect is the need of safety-related systems. During the FP6 EASIS project [3], a number of hardware and software architectures for integrated safety systems were proposed. In particular for the more safety-relevant systems it was determined that a degree of redundancy in the power supply is needed. Whilst not a primary research focus of EE-VERT, the architecture to be proposed will incorporate support for such requirements.

Finally it is envisaged that a distributed network of smart components will require some form of standardised communications to permit the exchange of energy-related data. It is anticipated that EE-VERT will create the possibility of self-organising networks of smart components, and will therefore develop requirements for such communications that can be offered for international standardisation through a body such as ISO.

3 Conclusions

This paper has presented the approach to energy efficiency and CO_2 reduction that will be developed during the EC-funded EE-VERT project. Central to the EE-VERT approach is the deployment of an overall energy management strategy in road vehicles that will integrate novel concepts for power generation and smart actuators, as well as permitting the integration of concepts for energy harvesting being developed elsewhere. While the focus of EE-VERT is vehicles with a conventional powertrain, EE-VERT will also realise improvements in hybrid vehicles that will assist in the deployment of cost-effective alternative-powertrain vehicles.

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