Energy Efficient Vehicles for Road Transport (EE-VERT)

Abstract

Road transport is the second largest producer of greenhouse gases within the European Union. This project, Energy Efficient Vehicles for Road Transport (EE-VERT) had an objective of a 10-12% reduction in fuel consumption and CO_2 generation for conventional vehicles at an attractive cost-benefit ratio. The central EE-VERT concept is the electrification of auxiliary systems, operating them demand oriented and supplying their energy from energy sources such as recuperated braking energy, waste heat recovery or solar cells, using an overall energy management strategy. To achieve improved efficiency and power the generator operates at 40V and to connect the elements to the standard electrical system a new architecture has been devised that works with 40V and 14V levels. The main components of the 40V network are a new generator based on the claw pole technology with integrated permanent magnets, a Li-Ion battery system and a DC/DC converter with multiple inputs (MIPEC) for interfacing between the two voltage levels and the additional energy sources such as the solar panel. The available generator power during recuperation is up to 11kW. The efficiency of the new generator is above 80% in the low range of speed while in the high range of speed the efficiency is still above 70%. The MIPEC efficiency is around 94%. The simulation work indicates that average fuel savings of 10% for real life driving cycles and up to 20% when the start and stop functionality is applied to real life urban cycles are possible and that real life urban driving cycles benefit the most from the EE-VERT concept. Fuel consumption results for the demonstrator car validated the simulation work, confirming that the EE-VERT concept can lead to fuel savings of 10-20% depending on the mission cycle for a modest increase in costs.

Introduction

Within the European Union (EU) road transport is the second largest producer of carbon dioxide (CO_2), one of the greenhouse gases responsible for climate changes [1]. While some improvements in efficiency of road vehicles have been achieved, continued growth in traffic and congestion mean that CO_2 emissions from road transport have grown overall. At the same time rising fuel prices and supply instability also give pressure for increased efficiency. The European Commission has a declared strategy to reduce overall emissions in particular of CO_2. Reducing the CO_2 generated by road transport is a key aspect of the strategy to reduce the production of greenhouse gases.

Hybrid Electric Vehicles (HEVs) offer good CO_2 savings but market penetration is slow. Full Electric Vehicles (EVs) are even further away from forming a significant proportion of the vehicle market. Consequently conventional vehicles will play a significant role for the next decades. But despite improvements in modern conventional vehicles, a considerable amount of energy is still wasted due to the lack of an overall on-board energy management strategy. Further electrification of auxiliary systems promises energy and efficiency gains but there is an additional need for a coordinated approach to the generation, distribution and use of energy. So there is a gap in the market between present conventional vehicles and HEVs/EVs (Figure 2).

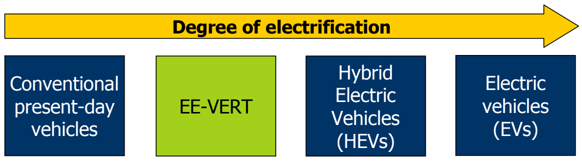


Figure 2: Market gap between present conventional vehicles and HEVs/EVs

EE-VERT (Energy Efficient Vehicles for Road Transport) is a project funded under the Seventh Framework Programme of the European Commission. In particular EE-VERT targets a 10-12% reduction in fuel consumption and CO_2 generation. EE-VERT is seeking to develop marketable energy saving technologies with an attractive cost-benefit ratio for conventional vehicles that have the potential for rapid launch and market penetration to bridge this gap.

System concept

Some technologies have been deployed to the market which addresses certain inefficiencies in road vehicles, for example electric power assisted steering (EPAS), electric air conditioning in Toyota hybrids, start-stop operation or regenerative braking [2]. Nevertheless, these technologies may be viewed as "islands" of improving energy efficiency, because they are not combined from a vehicle system point of view. For instance, regarding regenerative braking the power that can be recuperated during braking is relatively low because the power net voltage of 14V and the architecture were not optimised for this new function.

The central EE-VERT concept is the electrification of auxiliary systems, operating them demand oriented and supplying their energy by recovered and CO_2-neutral energy from energy sources such as extended recuperation of braking energy, waste heat recovery or solar cells. Figure 3 shows the basic EE-VERT approach.

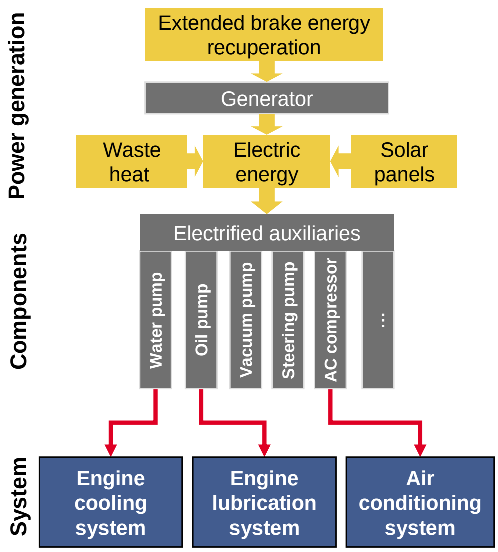


Figure 3: The basic EE-VERT approach [3]

The (engine) auxiliaries are mainly driven by the recovered electric energy. This strategy leads to the following benefits:

- Auxiliary systems can operate on a demand-oriented basis and fulfil their tasks in an optimised way;
- Less mechanical power demand on the engine;

- Less engine drag torque, leading to a higher capability for braking energy recuperation;

The optimised operation of auxiliary systems allows the thermal engine management and the air conditioning system to be enhanced. This leads to additional benefits for the fuel demand and for the convenience of vehicle users.

40V power net presentation and characterisation

In order to define an EE-VERT architecture, a number of candidate power net architectures were analysed. All of these gave special consideration to extended braking energy recuperation. The candidate architectures were analysed against a number of criteria including functional and component requirements, costs and the implications for functional safety.

Simulation studies in the project calculated that up to 8-11kW of power is the optimum power level that can be recovered during the braking phases for a standard passenger car. To collect this energy a high power and high efficiency generator coupled to a high power energy storage system is required. In addition energy can be recovered from other sources such as solar cells and waste heat in the exhaust gases.

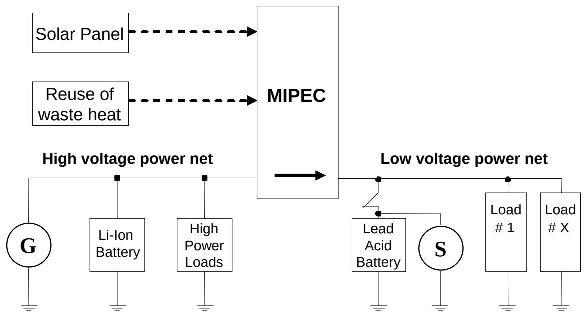


Figure 4: The EE-VERT power net architecture

To achieve improved efficiency and increased power the generator operates at a voltage higher than the standard 14V system. To avoid introducing additional safety measures the voltage should be less than 60V. To satisfy these requirements and to connect these elements to the standard electrical system a new architecture has been devised as shown in Figure 4.

Main components of the EE-VERT approach are a new generator with integrated permanent magnets, a Li-ion battery system and a DC/DC converter with multiple inputs for interfacing between the two voltage levels and the main components (Multiple-Input Power Electronic Converter - MIPEC). Central to the EE-VERT approach is the deployment of an overall energy management strategy permitting the integration of concepts for energy harvesting whilst using smart electrical auxiliaries.

Electrified auxiliaries reduce the load on the internal combustion engine (ICE) and can further reduce the overall energy consumption by only operating when required e.g. electrical vacuum pump or electrical water pump (EWP). An EWP enables the engine cooling water temperature to be increased from about 94-98C° to about 100-102C°. This is expected to increase the efficiency of the ICE by 2% leading to an additional reduction of fuel consumption.

System simulation

A simulation software “platform” has been developed using Matlab/Simulink which models the project reference car, an Alfa Romeo 159 jtdm as a physical model. This simulation model is based on models specifically developed for each of the new components mentioned and realistic models for the other elements in the vehicle. The aim is to compare fuel consumption in the actual car with the consumption in the “modified” car with new components and electrified auxiliaries. A further aim is the development of the system management strategy. Figure 5 shows the structure of the simulation software.

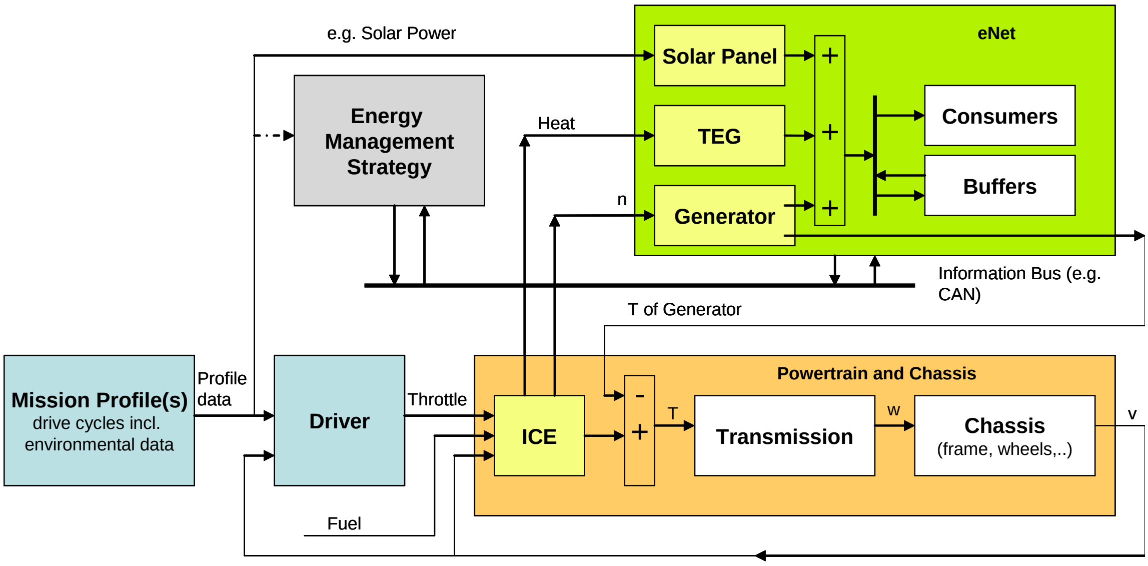
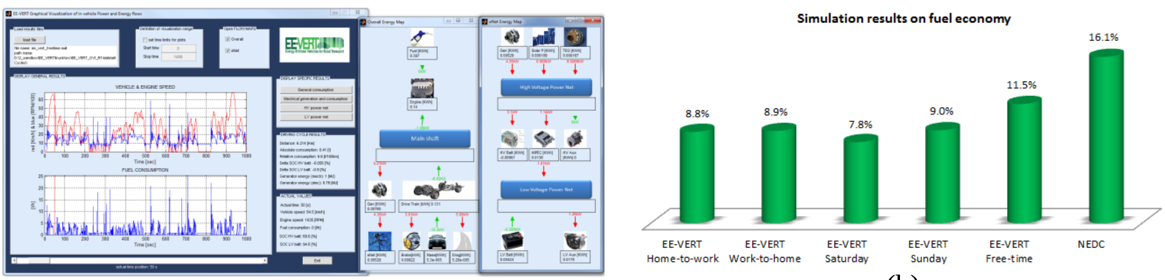


Figure 5: Structure of the simulation software

The reference mission profile of a passenger car was defined through the following activities:

- Collecting information from existing standards and state of the art real use cycle;
- Collecting information from the ARTEMIS project;
- Experimental activity on a vehicle for setting up an acquisition system;
- Experimental driving cycles in urban, rural and highway scenarios;
- Analysis of recorded data;
- Boundary condition definition through analysis of recorded data;
- Database of recorded missions available for future data integration.

The link between the mission profile and the operational mode of components has been investigated, particularly the impact of the EE-VERT real-life mission profile on generator, water pump, engine oil pump and the fuel pump. A statistical analysis of the mission profile has been done and possible improvements of the mentioned components were suggested. Furthermore a first working simulation (using a driver model) of the vehicle fuel consumption has been created. The simulation is capable of testing various mission profiles.



(a) (b)

Figure 6 System simulation (a) user interface for visualization of power and energy flows, and (b) results on fuel economy during real-life driving cycles (EE-VERT mission profile) and New European Driving Cycle (NEDC) by application of the EE-VERT concept

The new generator

The new generator concept is based on a claw pole machine with integrated permanent magnets for flux influence [Figure 7]. The main characteristics of this concept are an increased efficiency during standard operation and a peak output of up to 8-11kW during braking phases of the vehicle.

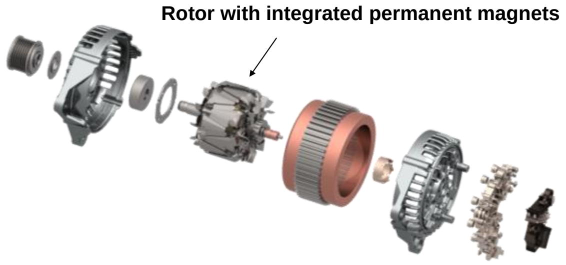


Figure 7: Exploded view of the generator prototype

Simulation was used to investigate the maximum power characteristic of the proposed design for the new generator on the mission profile real-life cycle. The results are shown in Figure 8.

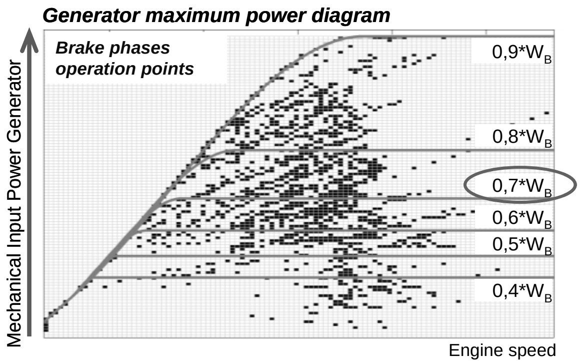


Figure 8: Identification of the optimal power performance of the new generator

The brake phases operation points show the available maximum recuperation energy for each braking phase. The simulation study demonstrated that an electric machine with around 10kW is required to recuperate around 70% of the available braking energy (W_B) during the whole cycle. If this can be realised it provides an attractive cost-benefit ratio for the new generator.

Due to the promising characteristics from the simulation analysis the new generator concept has been transferred into prototyping phase and was tested on a generator test bench. Figure 9 presents the maximum power characteristics of the new recuperation generator prototype: output current (IG), torque (MD) and efficiency (eta). The graphs were measured on a generator test bench. The red graph shows that the maximum generator current is up to 270A while the voltage is about 40V. Consequently the available power during recuperation is up to 11kW with this prototype generator. The efficiency is about 80% in the low range of speed while in the high range of speed the efficiency is still above 70%. An important feature is that there is only a slight increase in the dimensions compared with the standard generator.

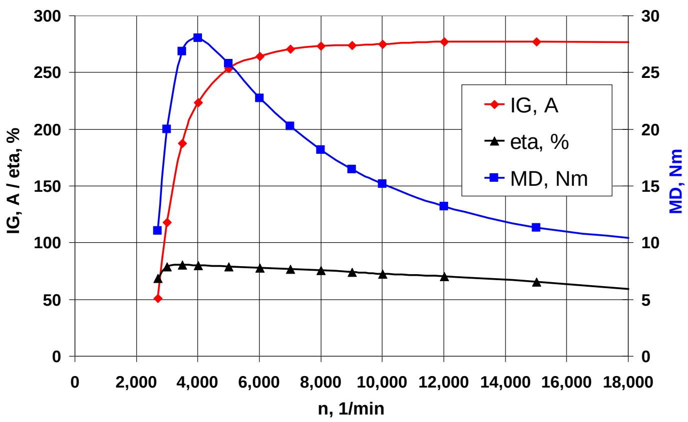


Figure 9: Maximum power characteristic of the new recuperation generator at 40V

40V Li-Ion battery

A working group drawn from the project partners was convened to consider the storage technologies. The conclusion was to use a Li-Ion battery operating at 40V (nominal) with a capacity of 64Ah for the main solution. With a target maximum recuperation power of 8kW the storage device has to be able to tolerate a charging current of up to 200A. The proposed 40V Li-ion battery is based on 8Ah lithium iron phosphate cells from LiFeBatt with 12 cells in series giving a nominal voltage of 39.6V (3.3V/cell) and 8 cells in parallel to accept a maximum charge rate of 200A (25A/cell). This results in a maximum charge power of 8.8kW and a 64Ah capacity. The maximum charging voltage is 3.65V/cell, giving a maximum battery charging voltage of 43.8V.

The design includes a battery management system that provides charge balancing, current, voltage and warning signals for under-voltage, over-voltage for each layer.

DC-DC converter conf

One of the main components of the EE-VERT approach is a DC-DC converter with multiple inputs for interfacing between the two voltage levels and the different power generation sources (Multiple-Input Power Electronic Converter - MIPEC). Developed by LEAR under the EE-VERT program it is the element in charge of connecting the different generation/storage elements working at different voltages and provides power to the conventional loads and the lead-acid battery. The MIPEC has been designed based on the following requirements:

- The power sources (generation and storage) are allowed to deliver power simultaneously.
- The power sources (generation and storage) may have different voltage/current variation ranges.
- Current flowing from/to each component is controlled.
- Design should be as compact as possible while maintaining flexibility on input types.
- Maximize conversion efficiency for “non-free” energy (i.e. energy obtained from fuel-consumption).

The internal structure of the MIPEC is shown in Fig. 4.1.

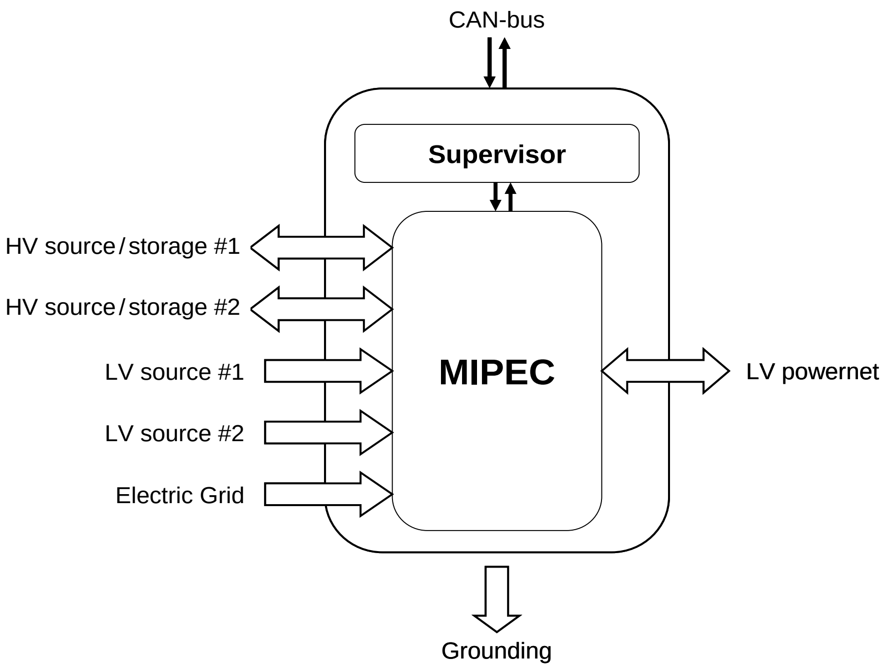


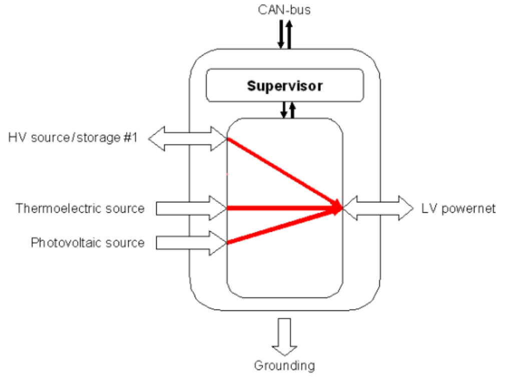
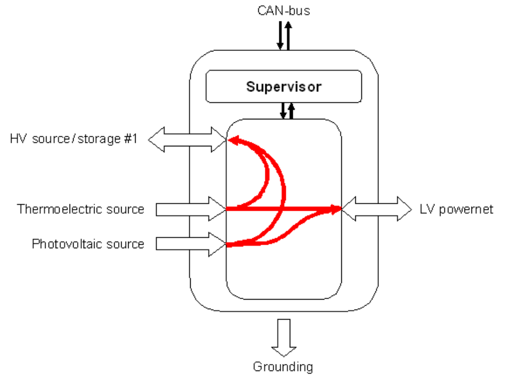
Figure 4.1: MIPEC Block Diagram

The MIPEC is built using two main blocks:

- Supervisor/Control/Communications board. This board includes a microprocessor for digital control of the power plant. It also includes the communication interfaces required for communication with rest of the car. Current prototype is interfaced through CAN and LIN.
- The Multi-input power electronics converter (MIPEC) itself. The MIPEC has an advantage over the conventional approach (with several stand-alone converters): the number of stages in the conventional structure can be reduced by recognizing redundancy in the power processing. In a multi-input converter, it is possible to share the system resources (i.e., conversion devices) and to remove the redundancy. As a result, the overall system efficiency can possibly be improved by eliminating redundant power stages and their associated losses.

Operation modes

The MIPEC is able to work in the following operation modes:

Direct conversion Any source available can deliver power to the output. Current flowing from any phase is controllable. This mode can be executed either with the engine running or stopped.	
Direct conversion + recharge from harvesting In this mode, energy is supplied by auxiliary (harvesting) supplies, such as the photovoltaic or/and the thermoelectric generator. This mode can be executed either with the engine running or stopped. If the load demand is lower than the energy generated by the sources, storage elements may be recharged using remaining energy.	

The system includes High-speed CAN-bus and LIN-bus for communication and a limp home mode for safety.

The mechanical design is shown in Figure 10. The system includes high-power input / output connectors for high-voltage (40V) and low-voltage power net able to support up to 1.5kW and medium power input / output connectors (700W) for the thermo-electric and photovoltaic generators. The system is designed to limit the power transfer between inputs and output (low voltage power net at 14V) to a maximum of 1kW.

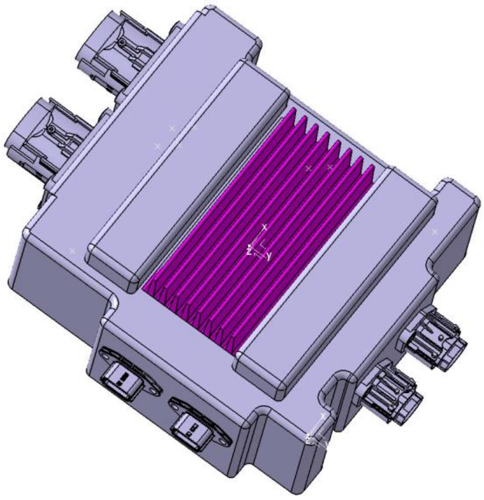


Figure 10: MIPEC preliminary mechanical design

Main features of the MIPEC are:

- digital control implemented in a power architecture;
- dual buck/boost with 3-phases interleaving each;
- integrated hardware protections (over-current/overvoltage/short-circuit);
- high efficiency.

It can be concluded that a new MIPEC DC-DC converter has been developed that can supply the 14V power net with up to 2kW with an efficiency higher than 93%.

New and improved actuators - Vacuum Pump

In the EE-VERT approach the mechanical unit is replaced by an electric vacuum pump (EVP) allowing full vacuum circuit performance for the evacuation of the brake booster. Although the efficiency of the electrified vacuum pump is less than the direct mechanical drive at maximum performance, it provides the ability to switch the electric vacuum pump off. From real life use it has been found that the vacuum pump is not required for most of the time leading to savings by switching off the vacuum pump when it is not needed. Experimental and simulation tests indicate a total reduction in fuel consumption of 1.5% with the electrical vacuum pump during several different drive cycles.

The EVP (Figure 11) is a dry running vane pump. This is especially useful for start-stop, catalyst heating, and hybrid vehicles during electric driving and free wheeling mode. It has a compact design at high flow rate performance with low pressure pulse with small box volume. It can provide stop-start- and free wheeling operation at full brake performance. A further advantage is that integration of the EVP on the vehicle is easier as it no longer mounted directly on the engine.

Figure 11: The electrical vacuum pump for the EE-VERT project

New and improved actuators - Fuel Pump

The current production fuel pump is based on a permanent magnet DC motor. Pressure is regulated through a passive pressure regulator: surplus fuel flow returns to fuel tank. The pump is always working at its maximum motor speed, regardless of the actual fuel rate required to meet engine performance.

The new management strategy regulates the fuel rate from the pump in order to assure the required engine performance and minimize the fuel recirculation. A small amount of recirculation is required in the common rail injection system. The regulation of the fuel rate is achieved through a current controlled driver applied to the fuel pump DC motor.

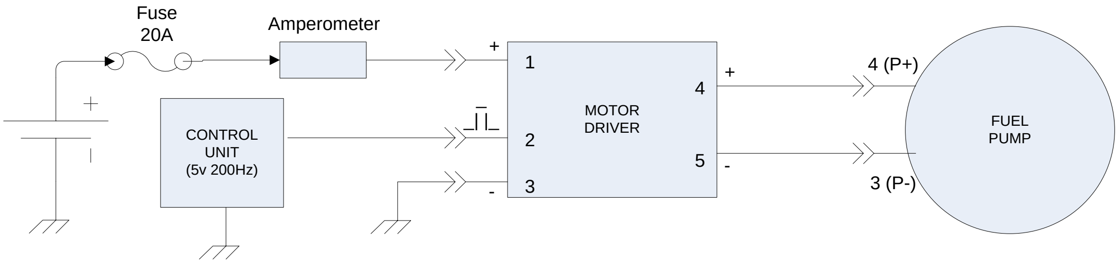


Figure 12 New fuel system architecture

The requirements for the fuel pump control are:

- To provide the minimum amount of fuel recirculation in the circuit;
- To deliver the required fuel rate to the high pressure fuel pump to meet required engine performance.

In most vehicle conditions maximum engine torque is not required, consequently maximum fuel delivery is not required. The fuel pump current required to sustain average fuel flow for average engine output is 3.5A. This equates to a saving of about 84W electrical (6A at 14V) and leads to a reduction of fuel consumption of about 1.1% both on NEDC and in real-life missions.

Energy management

Four energy management algorithms that control the generator have been evaluated. In the No Regeneration (NR) algorithm the generator always generates the energy that is needed by the electrical loads. The Baseline (BL), Equivalent Consumption Minimization Strategy (ECMS) and Dynamic Programming (DP) algorithms regenerate as much as possible when the vehicle brakes. This explains why they are better than the NR algorithm. The ECMS algorithm reduces the fuel consumption substantially compared to the BL algorithm for all investigated electrical load levels and driving cycles. The fuel savings are between 1.0 and 3.5 % when the electrical loads require an average power of more than 1000W. The ECMS algorithm generates energy at times when the price for generation is low and uses the battery at times when the generation is more costly. Finally, the differences in performance between the ECMS algorithm and DP algorithm are very small (less than 0.4 % for all investigated cases). This indicates that very little can be gained performance-wise by developing more complex algorithms that for example make use of information about the road ahead.

Cost-benefit comparison of modern powertrain concepts

To guarantee a marketable solution with a rapid launch and a fast market penetration EE-VERT is aiming to achieve an attractive cost-benefit ratio for the solution. A first estimation of the additional system costs for the EE-VERT approach was made from a vehicle manufacturer point of view. Furthermore a first cost-benefit analysis of the EE-VERT system with other powertrain concepts was drawn up. The achievable benefit of the EE-VERT approach on real-life cycle is between 7 and 10%. The total benefit on NEDC is estimated between 9 and 12%. The additional cost of the EE-VERT system has a target of 5% compared with 12-29% for HEV and >35% for EVs [4]. The cost-benefit comparison of current powertrain concepts shows that the EE-VERT concept has a very attractive cost-benefit ratio. HEVs and EVs have high additional system costs. The EE-VERT solution has the potential to bridge the gap between conventional vehicles and HEVs and EVs respectively by delivering a fast market launch and therefore an important impact to reduce the CO_2 emissions in Europe.

Applicability to Hybrid and Electric Vehicles

Hybrid vehicles have a high potential to reduce CO_2 emissions but they require cost-intensive and drastic technical modifications. EE-VERT has the objective to improve standard vehicles by an overall energy management approach using smart components with a moderate increase in costs. EE-VERT has developed a dual voltage architecture to accommodate multiple power sources and electrically driven auxiliary devices, and use predictive algorithms for the energy optimised operation of components and energy management. Table 1 shows the potential applicability of EE-VERT elements to micro, mild and full hybrid vehicle types.

Type of Hybrid	Micro	Mild	Full
Typical Voltages used	12V	30-50V/12V	150-450V/12V
EE-VERT Developments			
Dual voltage architecture		✓	✓*
MIPEC		✓	✓*
50V generator		✓	
40V Lithium ion battery		✓	
Electrified auxiliaries:			
A/C compressor actuator	✓	✓	✓
Engine cooling fan	✓	✓	✓
Fuel pump	✓	✓	✓
Vacuum pump	✓	✓	✓
VTG actuator	✓	✓	✓
Operating modes			
Brake energy recuperation	✓	✓	✓
Solar energy harvesting	✓	✓	✓
AC at idle or engine off		✓	✓
Ensure cranking ability of 12V SLI battery		✓	

*Multiple power source input concept

Table 1 Potential Applicability of EE-VERT Elements to Hybrid Vehicles

The influence of driver behaviour and the use of ITS on fuel consumption

The driver can have a large effect on the fuel efficiency of their vehicle; this is either by driving over the speed limit, not anticipating traffic flow or generally being unaware of modern eco driving techniques. This effect can equate to around a 15% increase in fuel consumption, which has the potential to immediately eradicate the proposed benefits derived from EE-VERT technologies.

Many of the recommended practices for eco driving techniques are also considered beneficial for reducing electrical energy consumption from the battery, or maximising energy recovery during deceleration, or increasing the time spent in electric mode (i.e. when drawing power from the batteries rather than internal combustion engine). These techniques and their effect are summarised in Table 2.

	Energy Recovery	**Energy Efficiency**	**Time in EV Mode**
Limit to 50% Throttle	—	↑	↑
Obey Speed Limits	—	↑	—
Engine Braking	↑	↑	↑
Avoiding Stops	↑	↑	↑
Anticipate Traffic Flow	↑	↑	—
Consistent Speed Profile	—	↑	—
Appropriate Gear Change	—	↑	↑
Smooth Acceleration	—	↑	↑
Limit Auxiliary Use	—	↑	—

Table 2: Eco driving techniques and their effect on 'Energy Recovery' during deceleration

Large bold arrow (↑) indicates large effect, small arrow (↑) small but positive effect, dash (—) indicates no effect.

Intelligent Transport Systems (ITS) have historically focused on improvement of traffic efficiency (reducing congestion) and safety (accident avoidance and mitigation). However recent developments have focused on how ITS can improve the energy efficiency of personal road vehicles. An EC report commissioned in 2009 suggested that 'Eco Driver Coaching' is the ITS technology that will have the biggest potential impact to reduce emissions by between 5 and 15%. This was defined as providing the driver with in-vehicle feedback to improve driving behaviours with additional information provided through enhanced GPS mapping.

Numerous aftermarket eco-driving coaching and advice systems are available for the driver to use. Broadly speaking these are either downloadable Smartphone applications ('apps'), or eco features which provide an 'added value service' on already existing platforms (such as Satnav systems). Additionally, with the development of hybrid and full electric vehicles a step-change with in-vehicle instrumentation has been necessary and adopted by vehicle manufacturers. With configurable LCD displays replacing the conventional instrument cluster, and the reduced need for conventional dials such as a tachometer and fuel level, vehicle designers have taken this opportunity to bring new information to the driver which has included feedback on driving behaviours.

The main EE-VERT concept proposes technological measure for the vehicle to reduce fuel. To complement this approach other driver-centred factors should be considered to maximise the potential benefits of the technologies being developed. The factors include in-vehicle driver coaching to inform and advise the driver, and also the use of enhanced GPS mapping to increase the situational awareness of the vehicle and appropriate power needs or battery state of charge. Without this the potential benefits derived from EE-VERT could be diminished by inappropriate or uninformed driver behaviours.

Safety Implications

The safety implications of introducing a dual-voltage architecture were also investigated at length. This work established a systematic process for analysing safety goals in order to derive functional safety requirements. These functional safety requirements are to be applied to both electrical loads within the vehicle and to the underlying electrical architecture and power generation system. Together this partnership forms a ‘safety contract’ to ensure that safety goals (at the vehicle level) are met. Generally, the process used fits within ISO 26262 “Road Vehicles – Functional Safety”, as a framework, although this has been expanded somewhat to accommodate new concepts such as the two levels of Functional Safety Requirements and the safety contract. These expansions allow the standard to be applied to more distributed systems and systems (such as EE-VERT) which provide a service rather than a vehicle level function.

Life Cycle Assessment

The aim of the Life Cycle Assessment (LCA) is to assess the environmental impact of the improvements to the electrical system of a passenger car proposed in the EE-VERT project. It involved a comparative study of the electrical system of the reference car and the EE-VERT modifications. The reference car was an Alfa Romeo 159 1.9 JTD. The components that were analysed for the reference car were the generator, mechanical water pump, VTG Actuator, vacuum pump and A/C compressor. The components of the EE-VERT demonstrator car includes a new generator, solar panels, DC/DC converter (MIPEC), extra wiring, current drivers for fuel pump and cooling fan , vacuum pump, A/C compressor and a Lithium ion battery ($LiFePO_4$). The mechanical water pump will not be exchanged for an electrical one, which means that the mechanical pump will be used in the demonstrator car as well. It was decided late in the project not to fit the new VTG Actuator in the demonstrator car. Therefore, it was only analysed as a single component and not for the whole lifecycle.

The life cycles of the two electrical systems were modelled in the software GaBi4.4. The model was parameterised, which means that it may be converted into an interactive report that may be used by non-expert LCA-users in the future.

The new electrical system weighs about 66 kg more than the one in the reference vehicle. If a linear relationship exists between the fuel consumption and the increase in weight, then the fuel consumption for the EE-VERT solution would be 0.067 l/km instead of 0.064 l/km (reference car). However, the electrical system is designed in such a way that energy will be saved. The actual fuel consumption of the EE-VERT solution was measured to be 0.059 l/km, which is a saving of about 7.5 %. The potential fuel saving during the lifetime (150 000 km) of the vehicle is 720 l of diesel.

The data for the components were of varying quality in the terms of detail regarding number and type of materials, which might influence the results but not significantly. The solar panel was one of the new components that has a very large impact on the environment. However, it will probably most often be used in hot climates for cooling of the passenger compartment. It should also be kept in mind that the level of detail of the data for the solar panel was very good. The data had been collected for four steps of manufacture from the extraction of silicon to the manufacture of a module with 72 solar cells. However, the solar panel used in the car contained 36 solar cells, so the data was modified to fit that specification as closely as possible, which meant that the fourth manufacturing step was excluded. However, the difference was not significant. The power mix needed for the manufacture might be different in the future when solar cells may power the manufacture of new solar cells. Due to this and that the solar panels can be seen as an accessory of choice, it was excluded from some of the calculations to enable the comparison between the other components to be shown in more detail.

The level of impact on the environment is related to the weight of the component as well as its content of valuable metals like copper, aluminium, silver and gold. Even small amounts of gold and silver will have a significant impact with regard to the weighting method EPS (Environmental Priority Strategies). The impact on the environment of these metals is reduced by recycling

The change of the environmental impact (excluding the solar panels) with regard to

- Energy consumption (net calorific value) was a decrease of 7 %,
- Global warming (GWP, CML2001-Nov-09) was a decrease of 7.1%
- Acidification (AP, CML2001-Nov-09) was a decrease of 5.2 %. Acidification is a regional impact that is related to “acid rain” issues.

For the weighting method EPS (Environmental Priority Strategies), which takes into account the willingness to restore the resources used, the new EE-VERT electrical system would incur an increase in the Environmental Load Units of about 21 %, if 80-100 % of the valuable metals are recycled to 80-100%. The increase is mainly due to the use of more materials, especially gold and silver in the electronics (e. g. Printed Circuit Boards).

EE-VERT Concept applied to a City Bus – Simulation results

The Volvos Global Simulation Platform (GSP) contains a complete model of a Single Decker City Bus. This bus, which belongs to the Micro Hybrid label, has some new features compared to a conventional bus. All the major auxiliaries, except for the fuel pump, are electrified. Up to about 73 % of the total brake energy is regenerated, through a system that includes a generator and battery. New control functions also need to be developed. The regenerated energy is used only for auxiliaries and not for propulsion.

The simulations have been performed with a standard GSP driver, driving on a city road. The result of the fuel consumption for the EE-VERT Micro Hybrid bus is then compared with a conventional bus, driving on the same road and having the same driver. The fuel savings potential is found to be about 21%.

In the standard concept, the components used are Volvo standard hybrid components. Such a system includes a 160 kW peak generator and 4000 Wh battery. However, the Micro Hybrid system can be downsized to 70 % without reducing the fuel saving potential. It is possible to downsize to 50%, but then the fuel savings drop to 14%.

Conclusion

This paper has presented the EE-VERT concept and activities which are undertaken to realise energy efficiency and CO_2 reduction for conventional vehicles. This project is aiming to make a significant contribution to reducing CO_2 emissions of conventional vehicles in road transport service. Central to the EE-VERT approach is the deployment of an overall energy management strategy in combination with the electrification of auxiliaries driven by recovered energy, along with an optimisation of the auxiliary systems. Furthermore, the concept provides additional convenience and functional benefits which increase the acceptance for necessary system changes and costs. Technologies such as those to be developed in the EE-VERT project are a key part of achieving the required CO_2 reduction targets. 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.

Acknowledgements
EE-VERT (Energy Efficient Vehicles for Road Transport) is a project funded under the Seventh Framework Programme of the European Commission, Grant Agreement number: 218598.

Partners: MIRA Ltd, Volvo Technology Corporation, Centro Richerche Fiat, Robert Bosch GmbH, Lear Corporation, Engineering Center Steyr, FH Joanneum, Universitatea Politehnica din Timisoara, Beespeed Automatizari

Website http://www.ee-vert.net

References

[1] European Environment Agency, "Green-house gas emission trends and projections in Europe 2008," in EEA Report No 5/2008.
[2] Voelcker, J. "2008 BMW 5-Series: Regenerative braking in a non-hybrid", part of Top 10 Tech Cars feature, in IEEE Spectrum, April 2007.
[3] Abele , M. et al, "Reduction of Fuel Consumption in Conventional Vehicles by Electrification of Auxiliaries," in Proc. 21st International AVL Conference Engine and Environment, 10th – 11th September, 2009, Graz, Austria.
[4] European Commission Joint Research Centre, "Plug-in Hybrid and Battery-Electric Vehicles", in JRC technical notes, Institute for Prospective Studies 2009.