ISSN 1691-5402
ISBN 978-9984-44-071-2
Environment. Technology. Resources
Proceedings of the 8th International Scientific and Practical Conference. Volume I1

FUEL CONSUMPTION REDUCTION BY USE OF HYBRID DRIVE SYSTEMS

Folker Renken
Jade University, Department of Engineering, Power Electronics
Friedrich-Paffrath-Str. 101, 26389 Wilhelmshaven, Germany
Ph.: +(49) 4421 985 2265, fax: +(49) 4421 985 2649, e-mail: folker.renken@jade-hs.de

Abstract. *Vehicles with hybrid drive systems are characterized by their driving dynamics, their energy efficiency and their environment-friendliness especially. Dependent on the electrical power and the drive train structure these hybrid drives are grouped into different classes. Designations such as micro-hybrid, mild-hybrid, full-hybrid, serial-hybrid, serial/parallel-hybrid or power-split-hybrid reflect the large variance of these different drive train possibilities.*
In hybrid drive systems electronically controlled converters take an important role. With such a converter also the energy exchange between electrical power system and electrical machine is regulated. The reduction of the vehicle fuel consumption here is of special interest. Today's hybrid vehicles use for the control mainly information from the present driving conditions, taking into account the actual electrical power system-charge as well as the power demand of the driver. With such a control already considerable fuel reductions are reached. But additionally superimposed control and information systems promise substantial potential for more fuel reduction. With these systems an outstanding energy-saving and anticipatory way of driving could be realized. The aim is to find the best operating point in each case for the combustion engine and to adapt the charge state of the electrical power system to the respective driving situation.

Keywords: *Hybrid electric vehicle (HEV), Automotive power train topologies, Automotive electrical system architectures, Battery energy management, Automotive electronic.*

Introduction

Developers in the automotive industry are testing again and again options to improve the driving dynamics and the fun factor of motor vehicles. Directly associated to these demands is the installed power and its direct use. Despite these requirements the fuel consumption and the emission of automobiles must be reduced further in the future. These apparently contrary demands can be very well achieved with a hybrid drive system - the combination of a combustion engine with an electrical machine. This new drive concept for automobiles makes many new functions possible, which can reduce the fuel consumption and the exhaust emission and in addition increase the travelling comfort and the driving dynamics substantially.

In the last years in the technical literature different hybrid drive systems have been presented. The electrical power of these systems varied between that of a micro-hybrid, used for combustion engine start and for starting support, and that of a full-hybrid, used for electrical driving with a power of up to 100kW. For efficient use of the electrical power often two electrical machines in the automobile are to be integrated. In this way many different hybrid drive concepts for motor vehicles can be realized.

This report first shows different drive train structures and electrical on board structures for hybrid vehicles. Afterwards for the different system concepts the fuel savings achieved are described and compared with each another. Further possibilities for an efficiency increase are also discussed.

System Functions for Hybrid Electric Vehicles

Even though the electrical machine of a hybrid drive system in principle can be driven only in the generator or motor mode, a lot of more interesting modes of operation can be realized with a hybrid vehicle. These do not only reduce the fuel consumption and the technical wear, but

also increase the travelling comfort and improve the driving dynamics. Following list shows the most important modes of operation and functions of a hybrid drive system.
These functions effect a reduction of fuel consumption and of exhaust emission. But substantial electrical power is necessary for a noticeable support in the motor operation. For example in vehicles of the compact class an additional “boost-torque” is only discernible starting from 20Nm. This corresponds to a mechanical power of approximately 3kW at rotor speed of 1500rps [1, 4].

- **Cold start**
  Reduction of fuel consumption and emission during the start process
- **Generator mode**
  High efficiency during electric energy generation (e.g. 10kW with $\eta > 80\%$)
- **Stalling prevention**
  Starting support of the combustion engine at low speed
- **Boost mode**
  Support of the combustion engine at higher speed (e.g. during overtaking)
- **Regenerative braking**
  Energy recovery in delay and brake phases
- **Start-Stop mode**
  Combustion engine switch-off at idle speed with fast restart
  (E.g. within approx. 290ms)

A pre-condition for the combined operation of the combustion engine and the electrical machine is a high-capacity energy storage. This storage system must be designed for sufficient numbers of cycles because of the enormous start and boost modes over the life. With such a dynamic drive the energy storage system is subjected to a short-term load of direct currents of up to 400A.

Power Train Structures for Hybrid Electric Vehicles

The mechanical coupling of a hybrid drive system in the vehicle can be realized in different ways. On the one hand the electrical machine can be connected as a conventional generator. Here, the electric machine and the combustion engine are coupled by a belt (micro-hybrid). But if large torque and engine power has to be transferred a better mechanical coupling to the automobile’s power train is necessary. Fig. 1 shows different drive train structures of hybrid systems. In all these examples the electrical machine is integrated in the power train directly. In this way a good mechanical contact to the combustion engine is realized [2, 3, 4, 5].
The typical power train structure of a mild-hybrid is represented in figure 1a. The electrical machine is tightly coupled to the combustion engine. In this way, the required torque for starting the combustion engine can be transferred easily. During acceleration phases the engine can be supported electrically. Also, during deceleration and brake phases an energy recovery to the battery is possible. With an additional clutch, the typical structure of a full-hybrid concept can be realized (Fig. 1b). This configuration allows pure electric drive in addition to the functions of the mild-hybrid.
Figure 1c shows the drive train structure of a series/parallel hybrid. This system provides many functions. For example with an open clutch, the combustion engine can be started by the electrical machine 1. With a closed clutch (parallel operation) accelerating, decelerating and braking can be supported electrically. Pure electric drive (without combustion engine) is possible by machine 2 with opened clutch. If there is not enough energy stored in the battery, the series operation can be realized together with the help of the combustion engine and electrical machine 1. In this operation mode machine 2 is supplied by machine 1 electrically.

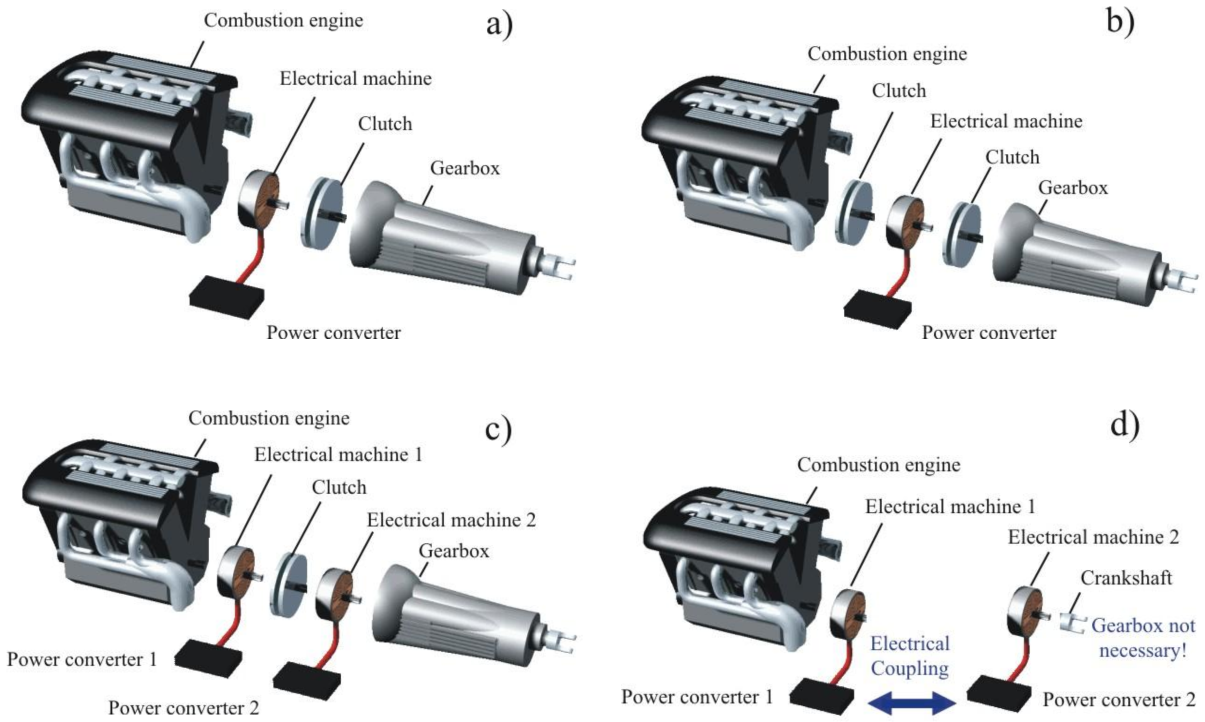

Fig. 1. **Power train topologies for hybrid electric vehicles**

A series-hybrid concept without transmission unit is presented in the figure 1d. In this concept, the combustion engine is connected only by two electrical machines to the crankshaft output side. The electrical dimension of machine 2 must be designed to drive the whole vehicle. This machine also allows energy recovery in deceleration and brake phases. A special example of a series-hybrid is the electric four-wheel drive. Instead of machine 2, four electrical machines, one for each wheel, are used. The machines are supplied electrically by machine 1. In this hybrid concept the mechanical components of the drive train can be reduced to a minimum.

Electrical Power System Architectures for Hybrid Electric Vehicles

Generally, hybrid drive systems are also used for the energy supply of the electric on-board power system inside the vehicle. For that reason the hybrid concepts have a substantial influence on the electrical system architectures. Fig. 2 shows typical electrical power system architectures for hybrid electric vehicles [3, 4].

A very simple power system architecture with only one dc-voltage level is represented in figure 2a. A DC/AC converter connects the electrical machine and the on-board power system. The electrical system voltage of 14V is just high enough to operate a micro-hybrid. To operate the more powerful mild-hybrids these vehicle electrical power system voltage must rise to 28V or 42V at least.

The typical on board system of a mild-hybrid is shown in figure 2b. Here the electrical machine is coupled by a DC/AC converter with a separate on board battery system. The voltage level of this power system can be increased up to 60V. For power supply of the 14V electrical system a DC/DC converter is used, which normally consists of a simple chopper. This electrical structure is equivalent to the typical on board power system architecture of a full-hybrid (figure 1c). But for full-hybrid electrical power systems the voltage of the storage is substantially higher. Also here the on board power system is coupled by DC/AC converter to the electrical machine and has to handle the high energy transfer. Today for full-hybrid electrical power systems voltages up to 650V are used. Consequently, the voltage isolation effort is larger. Furthermore a DC/DC converter with galvanic isolation must be used.

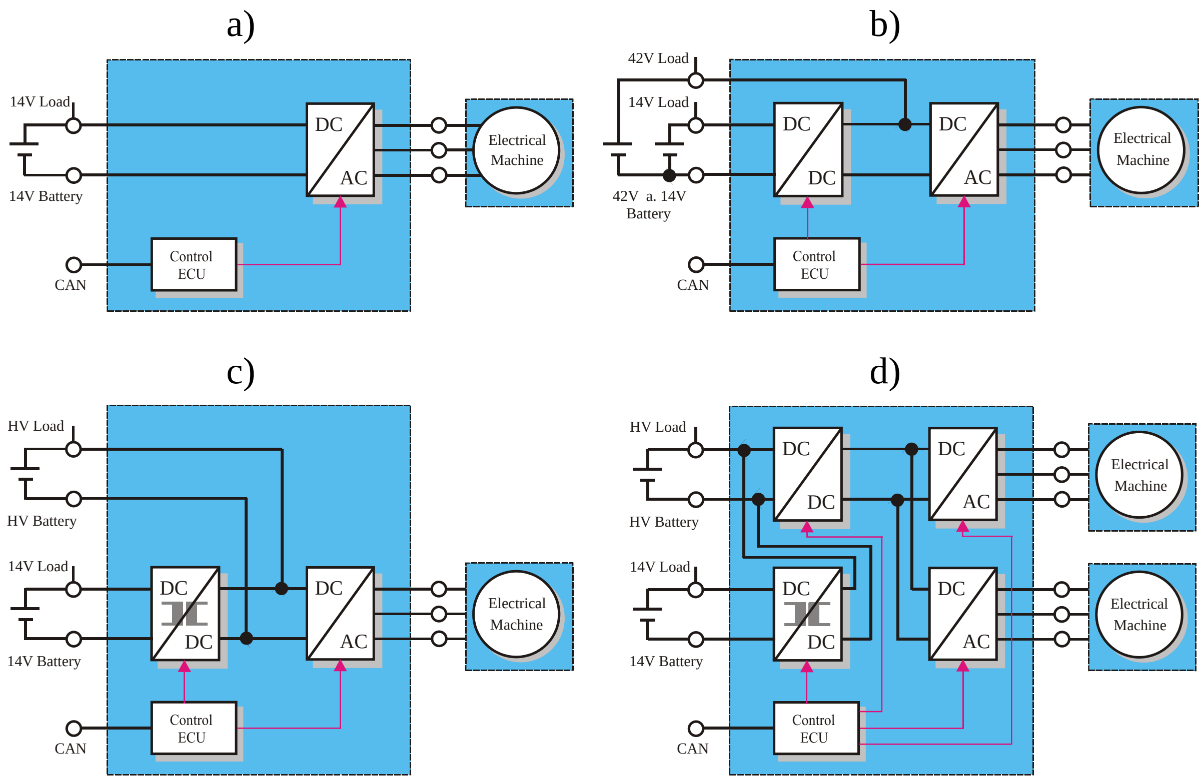

Fig. 2. **Electrical system architectures for hybrid electric vehicles**

A typical electric on board system of a series or series/parallel-hybrid is shown in figure 2d. Here two electrical machines are coupled electrically via powerful DC/AC converters to each other. This way the energy between the electrical machines can be exchanged in series operation on high voltage level. On the dc-voltage side these two converters are connected by a DC/DC converter to a high voltage energy-storage board-net. In this case a simple chopper can be use as DC/DC converter. In general the chopper is not designed for the complete power of a DC/AC converter. Theoretically the two DC/AC converters could also be connected to the energy storage directly. In this case the DC/DC converter would not be necessary. But due to the high electric power a high voltage level is preferred to reduce the losses. To generate this high voltage a series connection of many energy-storage cells is required. For supply of the 14V electrical power system another DC/DC converter with galvanic separation is necessary. Thus all high voltage hybrid components can be isolated correctly from the usual automobile on board power supply [5, 6].

Energy Management Strategies

With the first series hybrid vehicle introduction on the market the characteristics of vehicles with hybrid drive are increasingly discussed in public. In this discussion, the potential for the reduction of vehicle consumption is of special interest. Car manufacturers often emphasize the considerable reductions of consumption that can be achieved. This consumption minimization is reached by the combined operation of the different drive technologies in the vehicle. To achieve this, the present hybrid vehicles are using above all the information from the driving conditions. This procedure considers the actual battery charge as well as the power request of the driver. With these provisions the energy consumption can already be reduced substantially with the hybrid systems presented in Table 1 [1, 6].

Table 1.

System functions and fuel reduction of different hybrid concepts

Hybrid System	System Functions	Fuel Reduction
Micro - Hybrid 	- Start-Stop Mode - Regenerative Braking - Stalling Prevention	6 – 12%
Mild – Hybrid 	- Start-Stop Mode - Regenerative Braking - Stalling Prevention - Boost Mode	10 – 18%
Full – Hybrid 	- Start-Stop Mode - Regenerative Braking - Stalling Prevention - Boost Mode - Electrical Drive	16 – 25%

A further reduction of the fuel consumption and of the emission can be achieved by integration of information and communication systems. With the data collected in such a way the optimal operation for each moment can be realized with the help of an online energy management system. The following list shows some systems and criteria, which allow a more optimized energy-saving driving [7].

- Distance- and relativity speed in relation to the ahead-driving vehicle
- Traffic holdup identification by means of radio data information
- Information about the driving route: highs and lows, curve radiuses and sign-posting
- Information about the traffic light phase as well as the time of change over
- Local traffic holdup identification by means of vehicle to vehicle communication

Today the necessary information is partly already available. So the distances to the ahead-driving vehicle can be determined by means of distance sensors. Traffic holdup identification could be realized today by a simple evaluation of the radio traffic data information. Route information can be taken from a digital road map of the navigation system. While the maps today are still inexact and do not contain actual information about the road infrastructure, this will be different with the next generation of digital maps. These maps contain also street upgrade data, curve radiuses and sign-posting. In the medium-term it is also to be expected that information about the traffic light phase and the time until the next change of lights is made available. By automatic evaluation of all this information the saving potential of hybrid vehicles can be increased even further [6, 7].

Conclusion

In this article at first different drive train and electrical system architectures for hybrid systems were presented. To be able to realize many different hybrid systems, most manufacturers have opted for a modular concept with electronic devices. These devices consist in general of a battery, an electrical machine and electronic converters that are controlled by means of microprocessors. Thus during the operation not only the energy flow between storage and the electrical machine can be steered but also control-technical functions for example during the vehicle starting process can be taken over.

The present hybrid vehicles use mainly the information from the actual driving situation for the energy flow control, taking into account the battery charge and the power request of the driver. With this control concept today already considerable fuel consumption and emission reductions are reached. Further advancements could be achieved by integration of information and communication systems. So the efficiency of the hybrid vehicles could be increased by evaluation of further route information.

References

1. Renken F., Karrer V., Skotzek P. The Starter Generator – Systems, Functions and Components, 30th FISITA World Automotive Congress Barcelona, Spain 23-27 May 2004.
2. Renken F. Analytic Calculation of the DC-Link Capacitor Current for Pulsed Three-Phase Inverters. 11th EPE-PEMC Meeting Riga, Latvia 2-4 September 2004, Papers on CD-ROM ISBN 9984-32-033-2.
3. Renken F., Wolf J. Power Electronics for Hybrid-Drive Systems. 12th EPE Meeting Aalborg, Denmark September 2007, Proceedings on CD ISBN 9789075815108.
4. Renken F. Power Electronic Converter for Hybrid-Drive Systems. PCIM Conference Nürnberg, Germany May 2008, Proceedings on CD ISBN 978-3-89838-605-0.
5. Renken F. Multiphase DC/DC Converters for Hybrid Electric Vehicles. 14th International Power Electronics and Motion Control Conference, EPE-PEMC 2010 Ohrid, Republic of Macedonia September 2010.
6. Renken F. Power Electronics for Energy Generation and Storage Systems in the Automobile, Tutorial: Power Electronic in the Automobile, OTTI Technical-Workshop Regensburg October 2009 (in German).
7. Meinheit H., Benmimoun A. Anticipatory Energy Management Strategies for Hybrid Drive Systems, Innovative Concepts for Starter Generators, Expert-Verlag GmbH Würzburg, June 2004 (in German).