Hybrid system for a military 8x8 wheeled vehicle as an extension to a 120kW high-voltage energy system

Dr.-Ing. Carsten Greißner Jenoptik

Dipl.-Ing. Stephan Frank Jenoptik

Dipl.-Ing. Daniel König Jenoptik

Dipl.-Ing. Stephan Otto Jenoptik

Abstract

This article describes a parallel hybrid system for a military 8x8 wheeled vehicle, including high-voltage energy storage that is based on a 120kW high-voltage electrical energy system. At the beginning the target market will be described. The demands of the market have resulted in special features compared to 'conventional' passenger and commercial vehicle hybrid systems, which are shown. These features result in requirements at system level, which have been implemented with the aid of the system architecture shown in *Figure 1* and the individual components that are shown.

In order to realise the hybrid functionality, as well as the functions of the individual components a higher-order control unit is required, which is implemented in the form of a HYBRID CONTROL UNIT in the example that is shown. This control unit coordinates the power flow in the system and controls the individual components accordingly. Fault management also takes place at system level, so that system functionality can be deactivated after individual faults in the subcomponents without switching off the other subcomponents and their entire scope of functionality.

This hybrid approach was integrated into a Piranha 5 under the auspice of GDELS / Mowag. The abilities of this hybrid system have been demonstrated during various test rig and vehicle tests.

1. Introduction

The trend towards using hybrid systems in civil motor vehicles is also increasing in military vehicles. Because of ever-increasing protection requirements, the weight of the vehicles is increasing disproportionately. At the same time, good transportation capability is required for providing operational mobility.

Unlike the civil market, the main focus is on increasing the drive power, particularly in the low rpm range. The peak loads that occur during acceleration, for example, could be covered by the hybrid system. This would make it possible to use diesel engines with reduced power and less weight (downsizing). Other advantages would be energy savings due to brake energy recovery and start/stop capability, for example.

Due to the combination of the small quantity of military vehicles and the high military demands that are made, hybrid systems are expensive. The result as far as military vehicles is concerned is that hybrid systems such as this will only be used in expensive vehicles such as tracked vehicles and large multi-axle vehicles.

The high power requirements of significantly more than 100 kW represent a major challenge.

2. System structure

The hybrid system that is being described is an extension of ESW High Voltage Energy System that can distribute up to 120 kW electrical power to various external consumers using a bearingless Generator integrated in the drive train and a Generator Control Unit to stabilize the varying natural generator voltage. Among other things, these could be the 28V on-board power supply which is powered by the Vehicle Power Supply or providing energy for external consumers via a three-phase 400V AC network (export power) by the High Power Sinewave Inverter. In order to provide the necessary power quality for external consumers, the high-voltage intermediate circuit has been defined at 750 VDC (voltage-controlled). This means that a DC/DC converter (Battery Power Converter) is required to connect a high-voltage battery to extend the system to a hybrid system, to compensate for the varying battery voltage and distribute energy between the different voltage levels in a controlled way. The design of the system is shown in *Figure 1*: The electrical energy from the Generator is transferred to the high-voltage intermediate circuit via the Generator Control Unit (GCU), from where it is distributed to the various devices. Higher-order control of the system statuses and error handling are implemented in the Hybrid Control Unit (HCU). It also acts as a gateway to the vehicle computer.

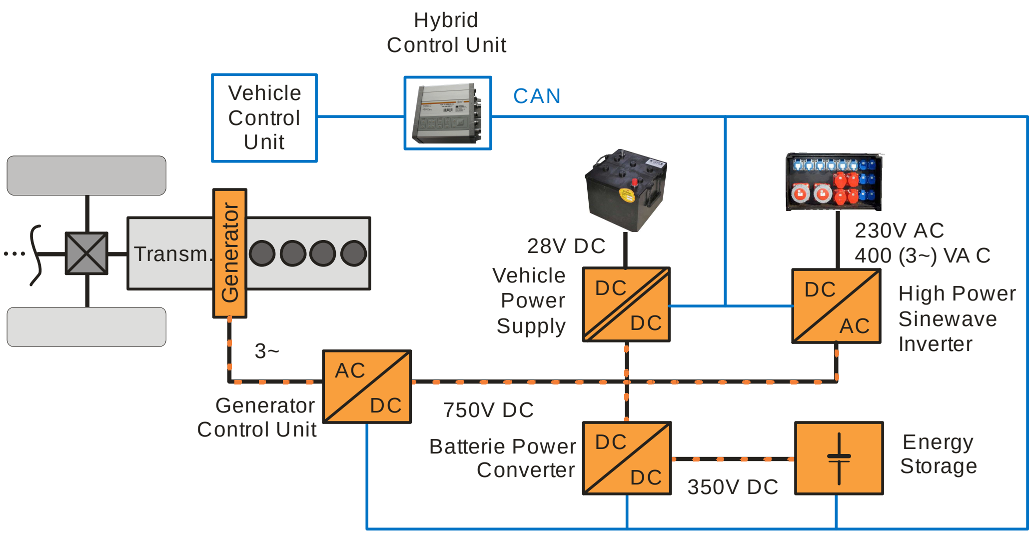

Figure 1: System design

Depending on the status of the diesel engine, different functions are possible within the extended hybrid system. *Figure 2* shows the different options and their transitions. Whilst the diesel engine is switched off, the high voltage battery can be used to power the 28V on-board power supply (silent alternator mode), and external consumers can be supplied (silent APU mode).

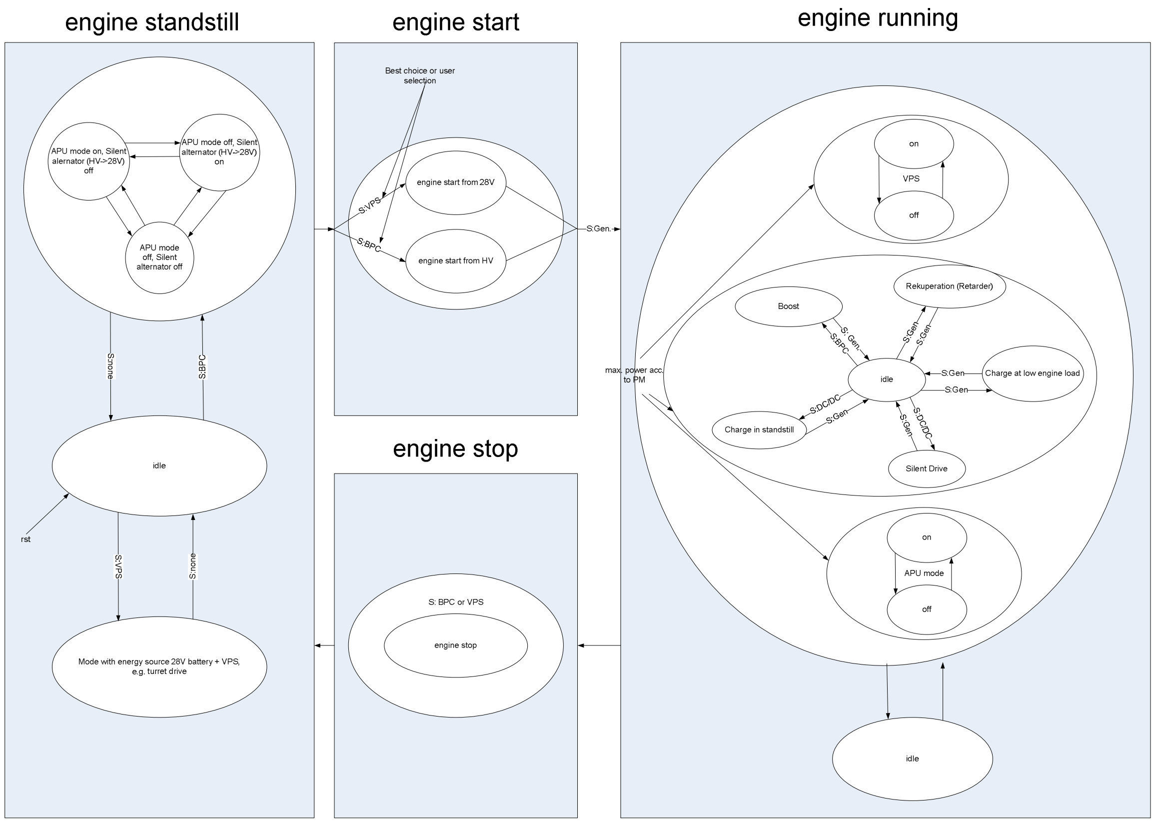

Figure 2: System statuses

The engine can be started via the 28V batteries or the high-voltage battery from this status. As soon as the engine has started, the hybrid functionality is available. Electrical propulsion (if the drive train is designed for it) and special charge modes for the HV battery are possible. At the same time, the 28V on-board power supply (VEHICLE POWER SUPPLY) and external 2-phase and 3-phase consumers (APU mode: 230 / 400VAC) can be supplied.

For each status there is a preferred source, from which energy flows into the activated consumer (energy sinks). For example, the preferred energy source with a switched off diesel engine is the high-voltage battery („S:DC/DC"). The source is switched to the 28V on-board power supply for starting („S:BNV") if this start mode has been selected. Whilst the engine is running, the generator is active as the source („S:GEN") by default, whereas the high-voltage battery is used as the source and the generator as the sink for boosting and several special statuses (motorised operation).

3. Functionality control

In order to actuate the different functions, each function has three possible statuses, which are shown in *Figure 3* as an example of source actuation. The potential statuses of sources and functions are identical, since sources are a sub-group of functions.

First the source or function can be selected. The source can be activated and deactivated again from here. If a fault occurs or a charge status or temperature limit is reached, for example, the source can switch to "not possible" status, meaning that the source is deactivated.

On the other hand there are the sinks, which obtain electrical energy from the high-voltage bus. Like the sources, the sinks can also adopt statuses, as shown in *Figure 3*.

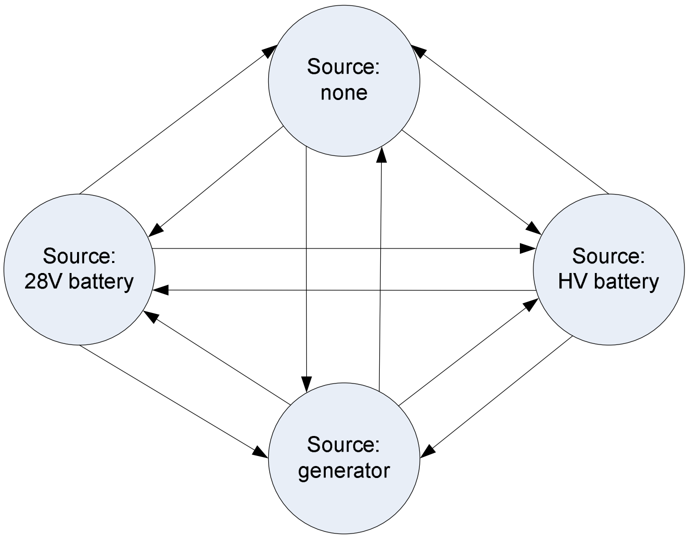

Figure 3: Source statuses

The following example should clarify this principle:

The vehicle is in "drive" status. Energy is being supplied to the vehicle from the generator and the Generator Control Unit. If the drive torque requested by the driver exceeds the engine torque that is currently available, this torque difference can be added to the drive train by the hybrid system if the current maximum permissible transmission torque is not exceeded.

In order to do this, the system switches to "Boost" mode, assumed that the required high-voltage battery with connected DC/DC converter („S:DC/DC") source is available (see *Figure 1*). When this occurs the energy flow is inverted, and the generator is driven as a motor by the Generator Control Unit and therefore assists the internal combustion engine (see *Figure 4*).

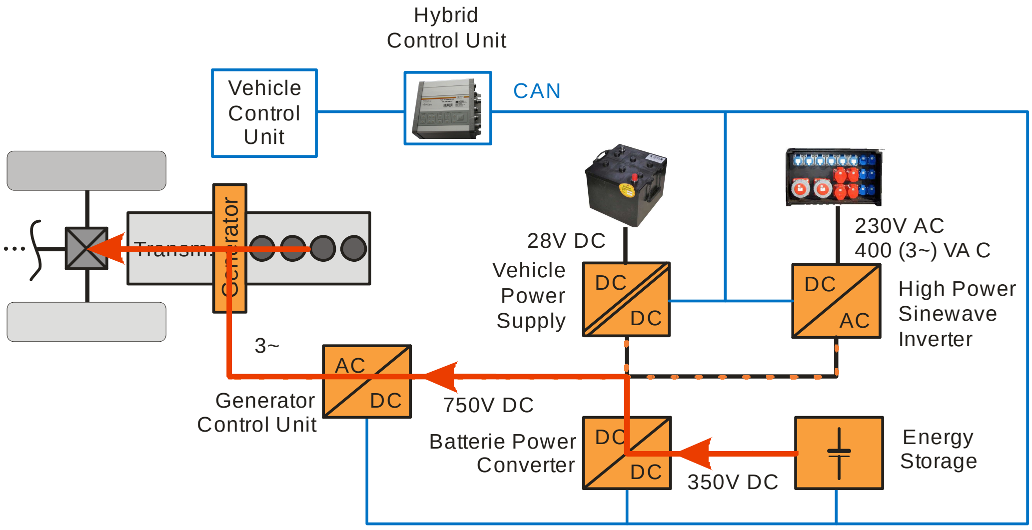

Figure 4: Energy flow during boosting

The hybrid system can provide this additional boost torque until the charge status (SOC - State of Charge) of the high-voltage battery has dropped below a defined value. If this occurs, the source "high voltage battery" with connected DC/DC converter („S:DC/DC") reverts to a status of "source not possible" and the system would automatically switch back to generator mode (Status „S:Gen").

4. Simulation

In order to reduce the effort of commissioning in the vehicle and for testing the handling of fault statuses by the HYBRID CONTROL UNIT, the newly developed hybrid functionality was started up in the original HCU as hardware-in-the-loop simulation.

This was done by simulating the vehicle and the energy system using two dSPACE MicroAutoBoxes, on which Simulink simulation runs for the drive train and the high-voltage energy system. The system design for simulation is shown in *Figure 5*. A control panel is available for user entries, and the speaker that is connected is used for acoustic engine speed feedback.

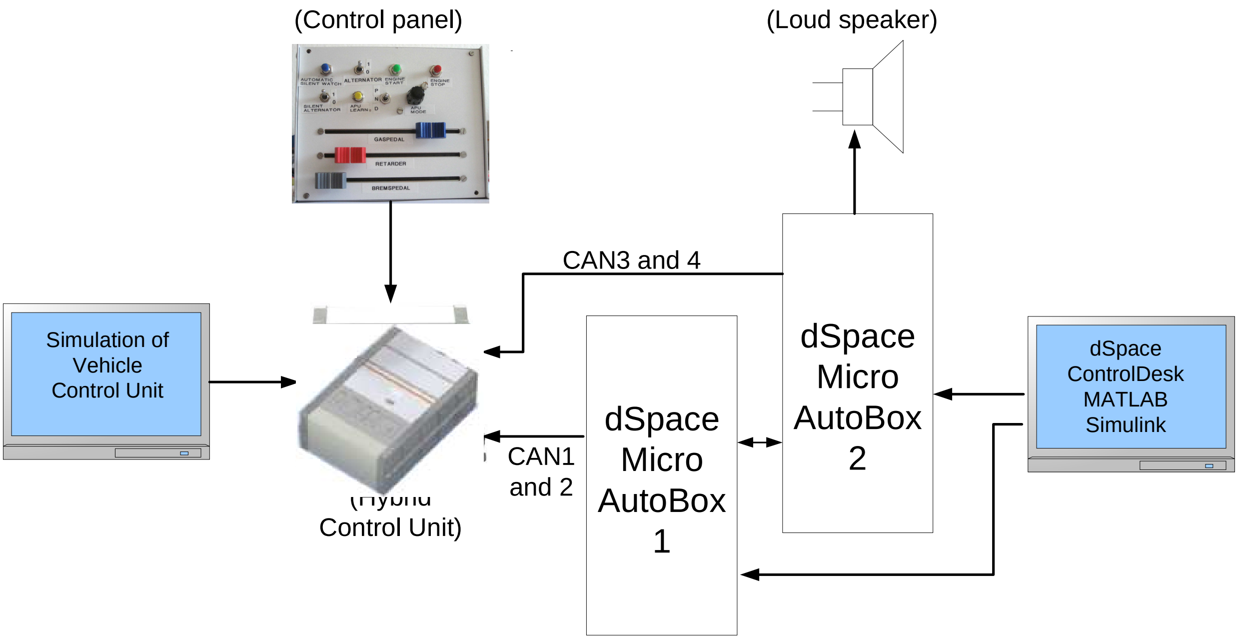

Figure 5: Basic design of Hardware-In-the-Loop simulation

4.1 Drive train simulation

The engine, the automatic transmission, the retarder and all other components that are relevant to the hybrid system are simulated in the drive train simulation. The design of the simulation model is shown in *Figure 6*.

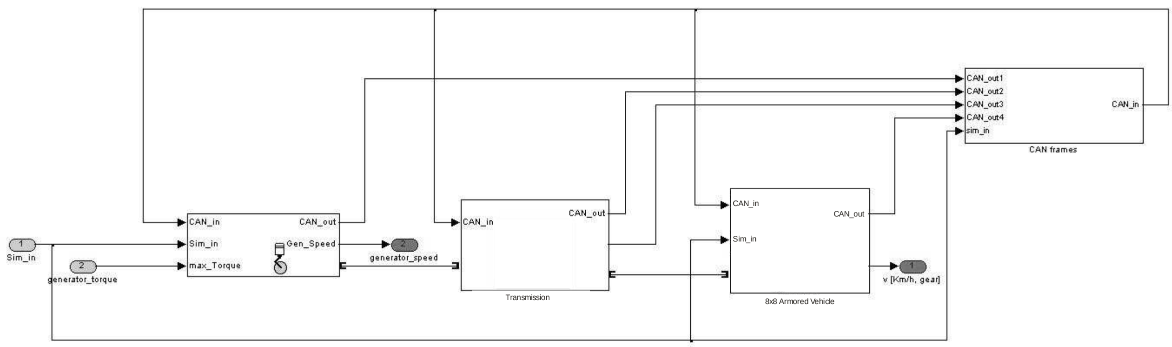

Figure 6: Drive train model

The characteristic curves of the diesel and the retarder are based on measurements. The automatic transmission was modelled including the torque converter and the lock-up clutch. This means that the speed curve during dynamic procedures such as acceleration and gear shifting procedures and particularly the torque limitation of the transmission can be simulated.

4.2 Simulation of the ESW HIGH VOLTAGE ENERGY SYSTEM

The simulation of the ESW HIGH VOLTAGE ENERGY SYSTEM includes the following components:

- Galvanically isolated 28V DC/DC converter (VEHICLE POWER SUPPLY)
- High Voltage DC/DC converter (BATTERY POWER CONVERTER)
- GENERATOR CONTROL UNIT
- HIGH POWER SINE INVERTER
- High voltage battery including Battery Management System
- 750 VDC intermediate circuit
- Digital signals (such as: parking brake, ABS etc.)

The simulation models of the individual components include the main physical properties and the realistic functional behaviour of the system. The high-voltage intermediate circuit is simulated using a discrete model of the entire intermediate circuit, including all passive components (capacities, inductances and resistances).

The CAN communication of the device has also been simulated, whereby attention has also been paid to the run times. This ensures that the hybrid control unit (HCU) communicates with the energy system via the CAN interface, exactly as it does in the vehicle (this is simulated using the MicroAutoBox).

4.3 Functional commissioning

The functional interconnections in the hybrid control unit are started up using the simulation. Each possible state transition is checked when this takes place. Furthermore, the system behaviour in the event of simulated faults can be checked and optimised so that partial functionality remains, even in the event of faults.

Starting up under laboratory conditions using hardware-in-the-loop simulation is needed in a system with this type of complexity.

The accessibility of all system variables makes it possible to carry out detailed analyses, particularly in the event of faults. This and the reproducibility of system statuses result in significantly better system optimisation and validation options than in a vehicle with extremely limited measuring options.

5. Simulation and Vehicle Test Results

The simulation results of a conventionally powered 8x8 wheeled vehicle are compared to those of an identical vehicle with a hybrid system in the following (see *Figure 7*).

Maximum vehicle acceleration occurs at time t=2sec. A speed of 100% is reached with the conventionally powered vehicle after 19 sec. If the drive train is assisted by additional electric motor torque, this speed can be reached after 15 sec. This means that the vehicle has more than 25% better acceleration with the same engine performance.

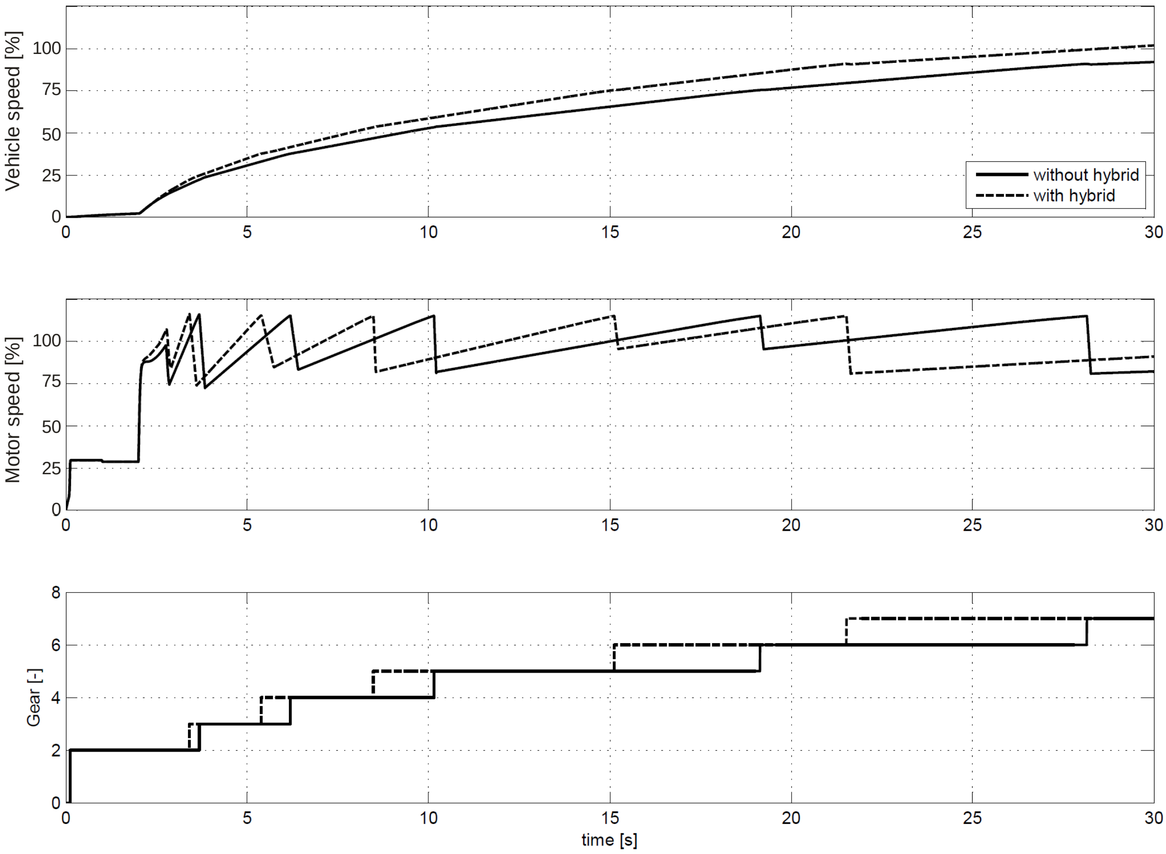

Figure 7: Simulation results with and without hybrid Boost

These simulation results are proofed by vehicle tests with a Piranha 5 from GDELS / Mowag depicted in *Figure 8*. The time to reach maximum speed (100%) is reduced by 12sec which means a reduction by 30%. This increased acceleration is in the same order of magnitude even if the compared velocity is only 90% of maximum speed. In this case a reduction of 8sec which corresponds to 27% is achieved. In conclusion an increased acceleration off more than 25% was proofed.

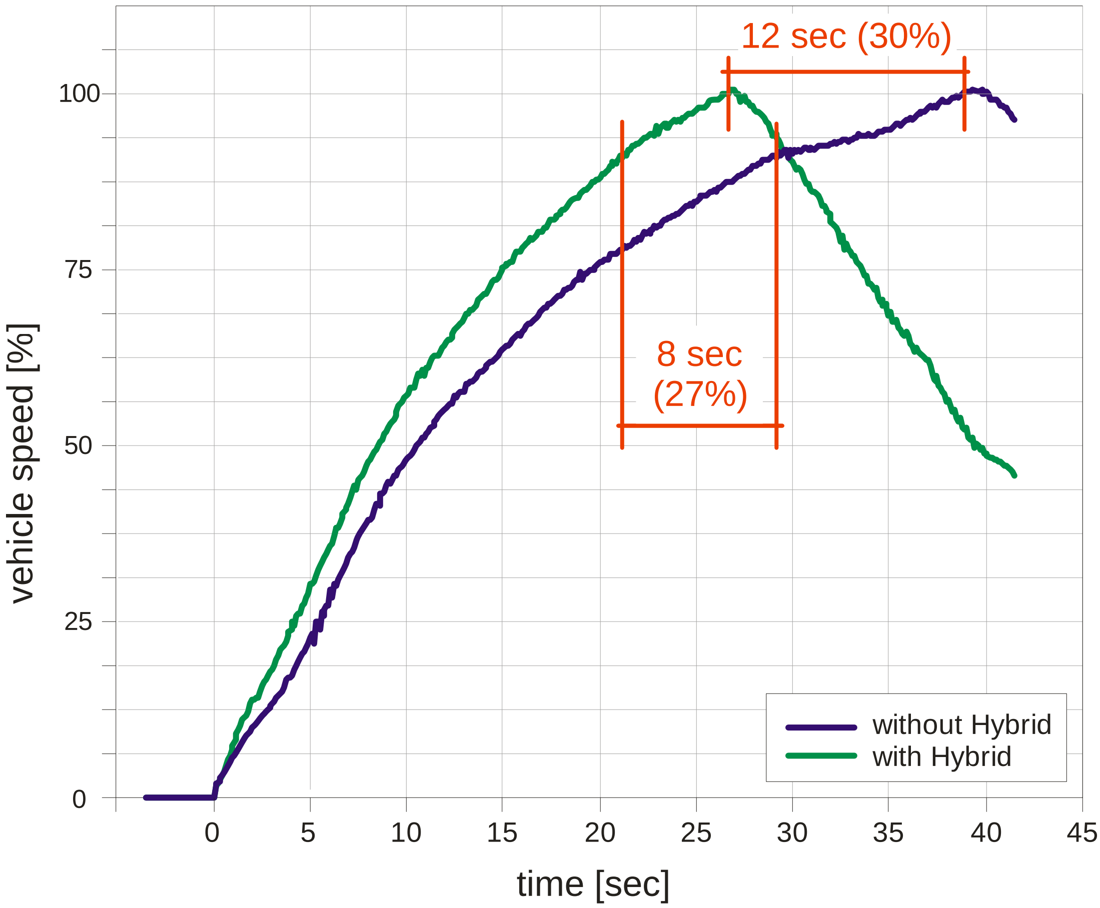

Figure 8: Vehicle test measurement results with and without hybrid Boost

Figure 9 shows the behaviour of the hybrid system during an acceleration phase. The green line represents vehicle speed up to maximum speed (100%). The corresponding engine speed is depicted by the blue graph. With every gear shift the engine speed is reduced followed by a new acceleration phase. For a smoother gear shift the additional hybrid torque is reduced during gear shift. The hybrid boost always takes place when the torque that the driver requests by throttle pedal is bigger than the actual available torque from the engine. As shown in *Figure 8* this occurs several times during the acceleration phase. A maximum addition hybrid torque of 500Nm is reached.

Subsequent to the acceleration phase the hybrid torque becomes negative which implies that the drive train is not any longer assisted by the hybrid system. In this phase the drive train is decelerated with 75% of maximum recuperative torque because the driver demands electrical braking. Vehicles kinetic energy is transferred into electrical energy by the hybrid system and used to charge the batteries.

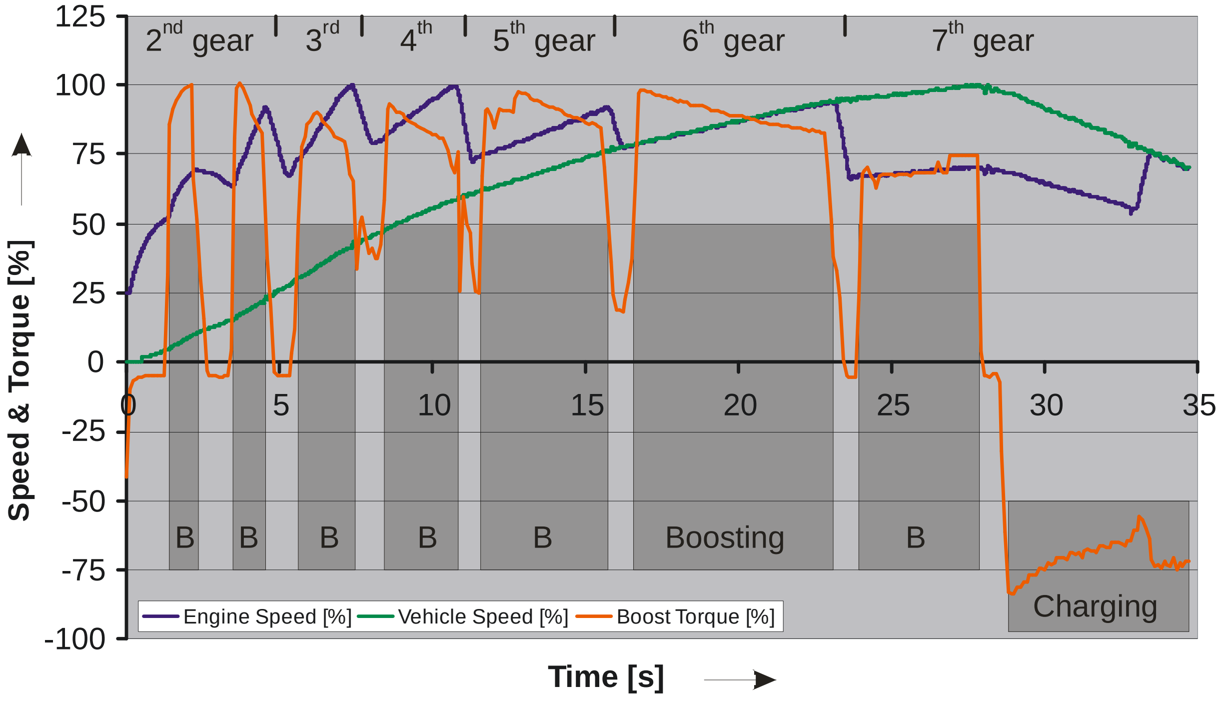

Figure 9: Vehicle test measurement results with hybrid Boost

Conclusion:

This major acceleration potential can be used in different ways. On the one hand, improved dynamics in critical situations such as driving off-road and faster acceleration from creep speed can have advantages. On the other hand, the weight of the vehicle can be increased without modifying the engine with the same dynamics. Another option is to use smaller engines, recuperate braking energy and therefore reduce fuel consumption and increase the range of the vehicle.

Authors:

Dr.-Ing. Carsten Greißner	Tel: 04103 60-3945	carsten.greissner@jenoptik.com
Dipl.-Ing. Stephan Frank	Tel: 04103 60-3682	stephan.frank@jenoptik.com
Dipl.-Ing. Daniel König	Tel: 04103 60-2453	daniel.koenig@jenoptik.com
Dipl.-Ing. Stephan Otto	Tel: 04103 60-3633	stephan.otto@jenoptik.com

Jenoptik – Defense and Civil Systems, ESW GmbH, Industriestraße 33, 22876 Wedel