Optimized CVT Hybrid

- **Research team at Technische Universität München developing special CVT hybrid powertrain**
- **Hybrid powertrain control based on a DS1005 PPC Board**
- **Simulation shows great energy saving potential**

A team of researchers at the Technische Universität München in Germany has developed a CVT hybrid powertrain that enables combustion engines to start up very fast. Another special feature is that it uses double-layer capacitors for energy storage. This hybrid concept is used to develop control algorithms for CVTs and for power management in hybrid vehicles. The algorithms are implemented and tested on two test benches and also in a prototype vehicle.

Working together with the companies GM Powertrain Europe, ZF Friedrichshafen AG and ZF Sachs AG, our team of researchers has developed a new kind of hybrid powertrain. The powertrain consists of a combustion engine, continuously variable transmission (CVT), electric motor and an electric energy storage module composed of double-layer capacitors (ultracapacitors). Used in hybrid vehicles, ultracapacitors are impressive in their great performance density and high efficiency due to low resistance. Moreover, they have a considerably longer lifetime than high-performance batteries.

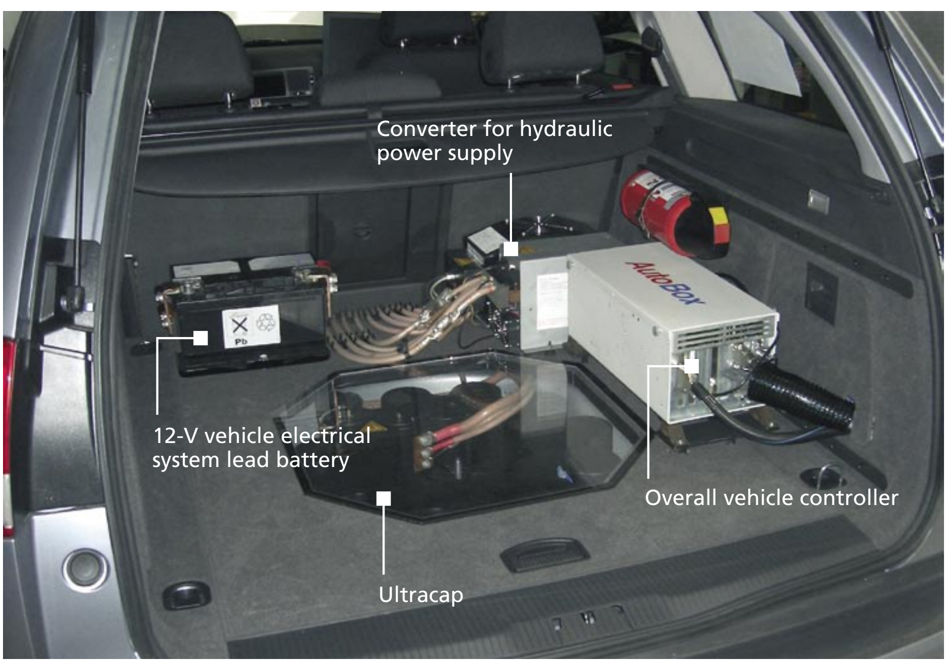
Running the Optimized CVT Hybrid

With the CVT hybrid, vehicle start-up is performed purely electrically, meaning that the combustion engine is decoupled and the electric motor propels the vehicle via the CVT variator. The combustion engine is then coupled in according to the current and expected powertrain status. The optimized CVT hybrid provides the ability to start the combustion engine very fast with a flywheel start. Rapid adjustment of the transmission gears brakes the electric motor. This makes the motor give off kinetic energy, which is used for starting the combustion engine very quickly and smoothly. During the flywheel start, the variable transmission can be used for the electric motor, and as the vehicle continues running, it is applied to the combustion engine by switching two toothed couplings.

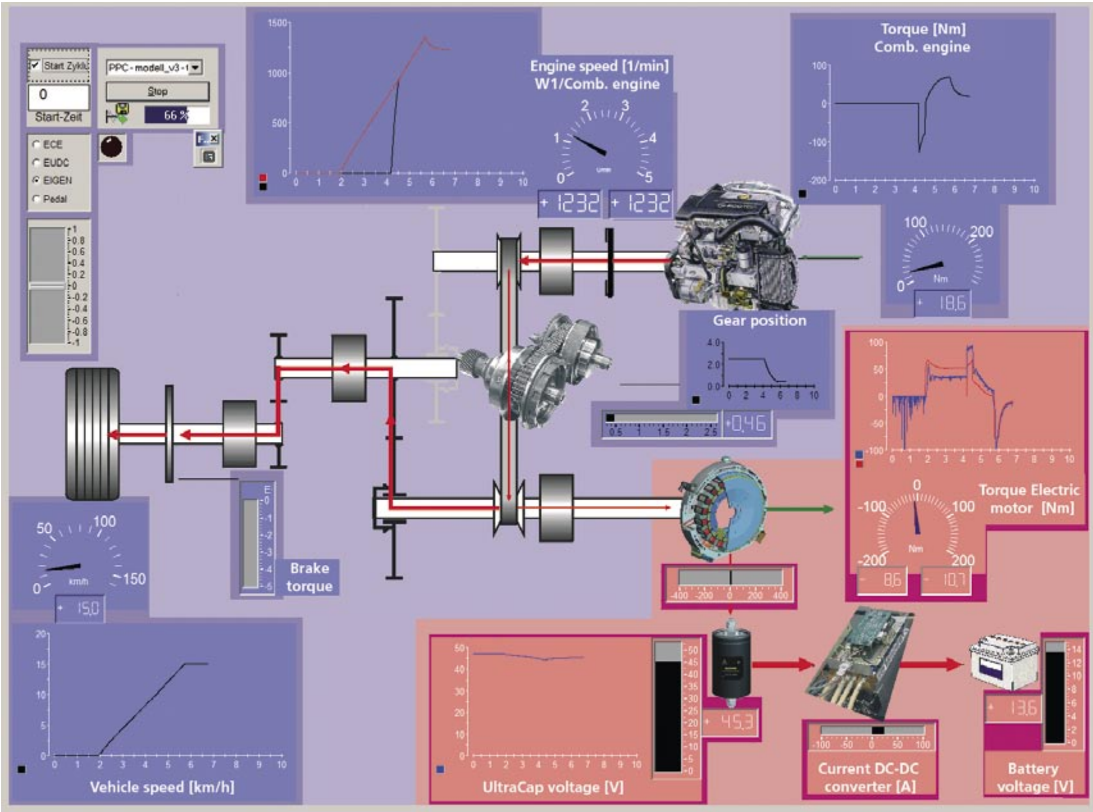
Control System on the Test Bench and in the Prototype Vehicle

The overall vehicle control and the control systems for the CVT variator and power management are developed on hardware-in-the-loop (HIL) test benches and in a prototype vehicle. The development and testing processes for the algorithms and control structures are iterative. We begin by evolving new concepts and modifications in MATLAB®/Simulink® and then test them by simulation.

▼ The ultracapacitors for energy storage and the dSPACE system are located in the trunk of the prototype vehicle.



We have installed one dSPACE system for each of the two control systems, with identical control hardware and software. The test benches accommodate the dSPACE system with a DS1005 PPC Board, CAN and multi-I/O boards in a PX10 enclosure. In the vehicle, the boards are housed in an AutoBox. Communication with the electronic control unit (ECU) for the combustion engine runs via the CAN interface that is available as standard. We split the CAN bus between the vehicle and the combustion engine to do this. We use a second CAN controller for communication with the vehicle CAN bus, and the dSPACE system simulates the other side in each case. Following successful verification, we apply the developed software directly to the test benches and the prototype vehicle. When new modifications and improvements



▲ *During operation, the power flows are visualized in the ControlDesk experiment software according to the structure of the optimized CVT hybrid powertrain.*

are made, these too are tested in the simulation. To visualize the power flow during test bench or vehicle operation, we used the powertrain structure as a basis for developing an animation in the ControlDesk experiment software, and this visualizes the power flows in the individual components.

Efficient Power Management

An important aspect of running a hybrid vehicle is to achieve optimum, consumption-reducing power management. Optimal control of the charge levels in the ultracapacitors is decisive here. The total system losses are calculated according to the powertrain structure and also by using the characteristics and look-up tables for the individual powertrain components. To identify the driving and braking behavior and predict it as precisely as possible, we use artificial neural networks. The additional information obtained in this way extends the procedure for loss minimization and improves power storage utilization.

> *"By using the dSPACE hardware in conjunction with MATLAB®/Simulink®, we can implement modifications to the controller structure very quickly."*
> ***Andreas Jörg, Technische Universität München***

We run the calculations this requires on the DS1005 PPC Board, which also executes the control algorithms for the overall vehicle control. Another challenge connected with the CVT hybrid is to coordinate the drives and couplings during the flywheel start. Test drives and measurements taken on the prototype vehicle show that combustion engine start-up occurs within a few tenths of a second and is imperceptible to the driver.

In the simulation, we already achieved a power saving potential of approx. 20% in a mixed European Drive Cycle. The aim now is to verify this by test bench trials and test drives with the prototype vehicle as the project continues.

Andreas Jörg and Jens Schlurmann
Institute for Electrical Drive Systems
Technische Universität München
Germany