Electric Mobility Makes Great Strides

626.6 kilometers under real conditions on one battery charge

Today, there are numerous research projects that focus on topics related to electric mobility. One aspect that is still considered a critical issue is the limited driving range of electric vehicles. The so-called "Schluckspecht" project holds special interest here; in the Solar Challenge 2010 in South Africa, a vehicle by this name covered 626.6 km – the longest distance an electric car has ever driven on a single battery charge in real traffic on public roads. This milestone was enabled by state-of-the-art drivetrain technologies and power electronics paired with highly professional implementation of the control and networking systems.

To build an electric car with a long driving range, optimizations are needed in all relevant disciplines. Necessary are a drive with high efficiency, light and compact batteries with large storage capacities (energy density), suitable power electronics, well-tuned control algorithms and efficient network communication. Of course, weight plays a crucial role here; this means that the mechanical construction of the chassis and body must be lightweight yet sturdy, and finally, safety aspects and in particular an effective brake system must not be neglected.

College project with a long tradition

The Offenburg University of Applied Sciences is also addressing this topic, and it can already reflect on over ten years of experience in electric mobility with its "Schluckspecht" student project. Team Schluckspecht has been participating in the European Eco Marathon since 1998, for example, a competition that gives special recognition to the most energy-efficient vehicle. In 2008, the "Schluckspecht III plus" concept vehicle took first place in the fuel cell category with a low equivalent combined fuel consumption of just 0.032 liters of Super gasoline per 100 km; this is equivalent to a distance of over 3,100 km on one liter of Super. Together with its research partners, the team developed all key components of the motor, chassis and wheel suspensions and systems ranging to the vehicle electronics.

Encouraged by this and other successes, the team decided to participate in the South African Solar Challenge, a competition for alternative drive vehicles. It is held on public roads around the Republic of South Africa, where many different hill grades must be mastered. Because the "Schluckspecht IV E" **(Figure 1)** is a purely battery-powered vehicle that utilizes lithium-ion batteries, the team was participating outside of the regular competition, but

Figure 1: Schluckspecht IV E at the Solar Challenge in South Africa.

under the official oversight of the FIA (Fédération Internationale de l´Automobile). The goal was to make the public aware of the performance capabilities of the direct drive system implemented in the Schluckspecht vehicle. In the end, a driving distance of 626.6 km on a single battery charge was officially documented, more than had ever been driven by an electric car under comparable conditions on public roads.

Wheel-hub direct drive with iron-free exciter coils

The success story of the Schluckspecht IV E, a variant of the fourth generation of test vehicles, is based on a drive concept with wheel-hub motors, which the University of Offenburg developed in collaboration with the Stuttgart-based engineering company Evomotiv. Together with its twelve lithium-ion battery packs, the vehicle weighs about 320 kg and is driven by two wheel-hub motors, each with 42 poles and two kW of peak power. It is an advanced development of the “Schluckspecht City” vehicle variant that preceded it, and it achieves a high level of efficiency using brushless DC motors. In this motor type, the rotor has permanent magnets, while the excitation windings are located on the stator.

A special aspect of the Schluckspecht motor is the iron-free construction of the stator and excitation coils. Together with the direct drive and a sophisticated drive control system, this motor exhibits some interesting characteristics. For example, there are no cogging torques at all, which would otherwise occur in a conventional construction that is not iron-free. Periodic cogging torques cause mechanical oscillations and speed fluctuations, and they reduce efficiency. A crucial advantage – besides a higher start-up torque and low-noise operation – is that the wheel turns with hardly any resistive forces in the deenergized, excitation-free motor state; this makes it possible to omit a separation clutch as well as a transmission, differential, etc. Since direct drives generate forward propulsion precisely where it is needed, the system attains an exceptionally high efficiency of up to 98 %. This engine concept was awarded the Bosch Innovation Prize in the year 2006.

Optimized commutation strategy with PWM drive control

Because of their brushless operating principle, wheel-hub drives operate nearly wear-free, just like inverter controlled asynchronous AC motors, which are the quasi-standard for industrial drive technology. One essential prerequisite, however, is electronic commutation, which ensures that the directions of the magnetic fields in the coils attract and repel the permanent magnets at the right times in alternation, based on the fundamental operating principle of all electric motors. A prerequisite for this, and especially for the starting commutation, is precise knowledge of the rotor position. Several Hall sensors are used to acquire the positions of the permanent magnets. From this data, an evalution unit generates four tracks (A, B, Strobe, Index) via a quadrature signal **(Figure 2)**, which provide all necessary information on the turning direction and rotor position to a downstream type TMS320 digital signal processor **(Figure 3)**.

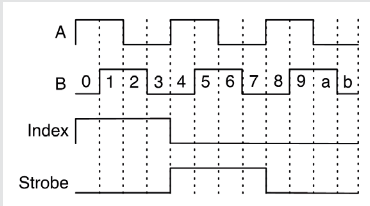

Figure 2: Quadrature signal

The signal processor, whose features include two CAN modules for interfacing with the on-board network architecture, generates two PWM signals that are phase-shifted by 180° **(Figure 4)** to control the power electronics. The bridge transition can be used to switch each excitation winding to the positive (T1, T5, T3) or negative (T4, T6, T2) link and control the direction of the current flow or magnetic field. The project engineers and students use a relatively high PWM frequency to compensate for the low motor inductance. From the perspective of the coil, the frequency is switched four times per PWM cycle. Furthermore, to recover energy during braking (regeneration), the system can be switched between motor and generator modes by changing the duty cycle. The special aspect here is that it is possible to work with an optimized commutation strategy using the four alternating states at half of the PWM frequency.

Evomotiv and the Hochschule Offenburg each set up their own motor test benches for measurement and test purposes, and to calibrate motor parameters independent of the actual vehicle **(Figure 5)**.

Networked electronics in the service of electric mobility

Basic elements of the Schluckspecht IV E electronic architecture are a central controller, a human-machine interface (HMI) ECU and several battery control modules. The latter continually monitor the voltage and temperature of the batteries. The central controller regulates the network of wheel-hub motors as a function of driver inputs or the HMI, and it also acts as the master for the battery control modules. In its role as master, the main controller can shut down the entire system very quickly in emergency situations by interrupting the energy supply. Moreover, this ECU serves as a central gateway (ZGW) for the vehicle's three CAN buses **(Figure 6)**.

Vehicle control responsibilities include both safety engineering and vehicle dynamic control tasks. They are fulfilled by providing a dedicated motor controller for each wheel-hub motor. Vehicle dynamic control includes synchronizing the drive wheels when driving through curves – since there is no mechanical differential – as well as monitoring wheel slip. Electronic communication is distributed among the CAN1, CAN2 and CAN3 buses. While CAN1 connects the human-machine interface to the central controller, CAN2 is responsible for battery control. Because these two communication areas are not time-critical, they utilize the Low-Speed transmission rate of 125 kBit/s. CAN3, on the other hand, is designed as a High-Speed CAN bus operating at 1 Mbit/s, because it networks the motor ECUs.

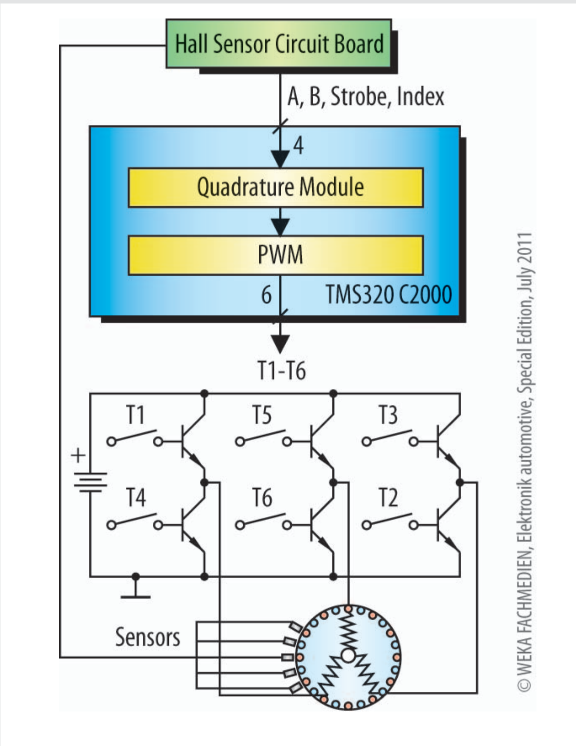

Figure 3: System diagram of motor/converter bridge/ processor

Remaining bus simulation enables parallel ECU development

During the development process for the ECUs and the software, the participants at the University of Offenburg and its partner Evomotiv were confronted with the problems that typically occur in complex communication structures. Typically, some developments are still in their beginning or prototype stages, while others are already further advanced. However, to test finished systems as realistically as possible developers must rely on the functionality of systems that do not exist yet– at least significant portions of them.

This problem is solved by what is referred to as a remaining bus simulation, in which appropriate software is used for computer simulation of the ECUs that do not exist in real form yet. The systems under test cannot detect any differences between simulations and real ECUs; therefore, full network communication is available. On the Schluckspecht project, CANoe from the company Vector Informatik was used as the standard analysis and simulation tool for this purpose. It is quite easy to create the remaing bus simulation using Windows software as soon as the responsible designers have fully and correctly parameterized the database for the network. The Vector Interaction Layer then ensures that every message is sent with the send type specified for it in the database.

From simulation to the real ECU

At the beginning of the project, the development team used this method to simulate over half of the ECUs of the Schluckspecht. The ECU applications created with CANoe's own CAPL programming language provide the foundation for the remaing bus simulation for great depth of testing, even without a vehicle. To test the

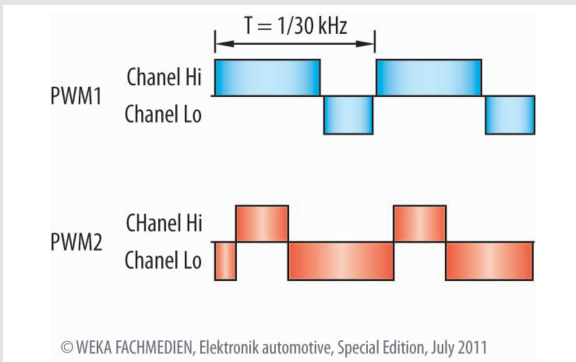

Figure 4: PWM signals for commutation

central gateway, for example, it seemed sensible to implement a special simulation interface. As the individual ECUs are gradually completed, the related part of the remaing bus simulation is simply deactivated. At the end of this process, the entire network is available in real form, and CANoe operates as a pure analysis and monitoring tool **(Figure 7)**.

On test drives of the Schluckspecht IV E, the same configuration that served as the basis for the remaing bus simulation in the early development phase later served to monitor processes inside the vehicle, and if necessary to intervene in them. All nodes are deactivated in the Simulation Setup of the CANoe configuration, since all ECUs now exist in real form. On the competition drive in South Africa, engineers and student engineers monitored such parameters as the temperature, voltage and current of the batteries, and they could set different drive torques over the various driving stages. The HMI panel can be used to display and stimulate the brakes and turn indicators.

Remote monitoring of test drives

Another interesting aspect of the Solar Challenge is that all monitoring and control activities are performed from a support vehicle. The challenge here is to transfer data from the on-board vehicle network to the analysis computer in the support vehicle by wireless transmission communication. This is accomplished by special CAN/WLAN interface modules with a range of up to 500 m that effectively mirror the entire CAN traffic of the test vehicle via WLAN to the remote network on the support vehicle. This process is fully transparent to CANoe; the tool can continue to be used to display and evaluate system parameters in the competition vehicle as usual. The time stamps of the CAN messages, which are preserved in the transmission, permit (time-)consistent display on the receiving end. This is also possible over the opposite pathway, and technicians can stimulate the test vehicle's network from the support vehicle. In this case, stimuli from the user control panel in the support vehicle have a higher priority for acting on the system than interventions by the driver. In extreme cases, the vehicle can even be fully operated by remote control.

FlexRay is entering the electric vehicle

Knowledge gained in these competitions quickly flows into advanced developments by industrial partners in the framework of knowledge transfer or into the university's own projects. Evomotiv has long been working together with the scientists from Offenburg on an improved wheel-hub motor for a street version of the electric vehicle. The focus here is on achieving a significant increase in motor power from two kW to 15 kW and four-wheel drive instead of two-wheel drive. For safety-relevant components, such as the brakes, various TÜV approvals are required. Here too, state-of-the-art technologies and innovations are expected to contribute to success. Consideration is also being given to a system with a voltage of 400 V to supply the motors instead of today's 48 V system. Moreover, the use of FlexRay is planned for time-critical communication between ECUs, motors and the brake system and to implement the related control circuits. FlexRay – characterized by such features as high speed, real-time capability and fault tolerance – places significantly higher demands on participants' expertise and on the development and analysis tools that are used. Simulation and analysis systems like CANoe are especially in demand, since they combine high performance with multibus capability, and they can simultaneously process and display both FlexRay and CAN data.

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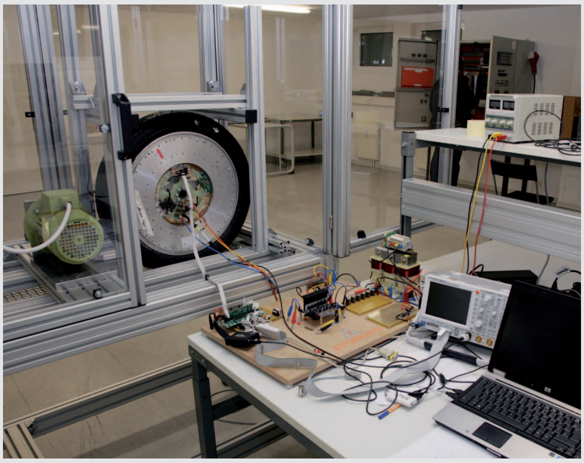

Figure 5: Motor test bench at Evomotiv.

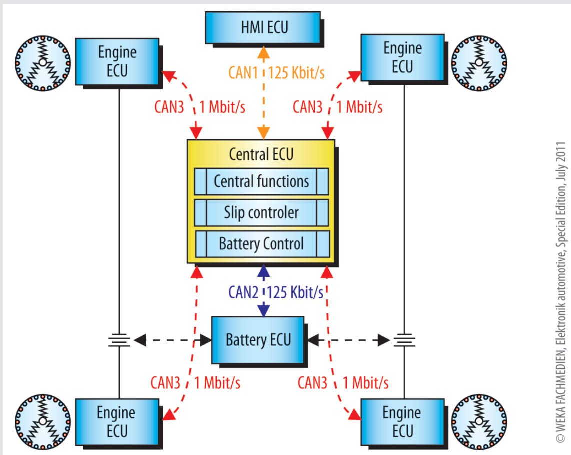

Figure 6: System overview of the full vehicle.

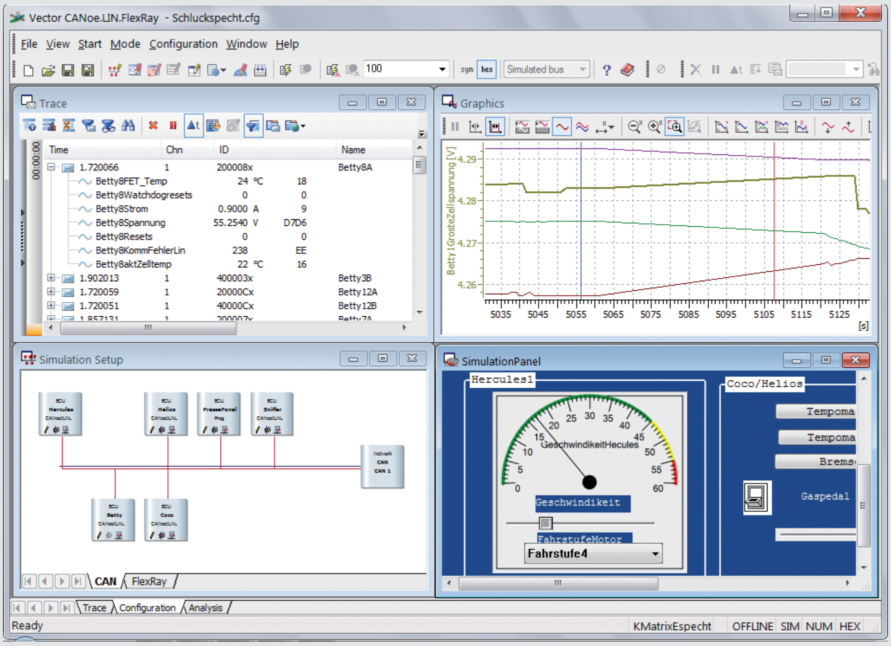

Figure 7: CANoe as analysis and monitoring tool.

Figures:
Offenburg University of Applied Science: initial figure
Evomotiv: figure 1, 2, 3, 4, 5, 6
Vector: figure 7

Links:
Homepage Offenburg University of Applied Science: www.fh-offenburg.de
Homepage Evomotiv : www.evomotiv.de
Homepage Vector: www.vector.com

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