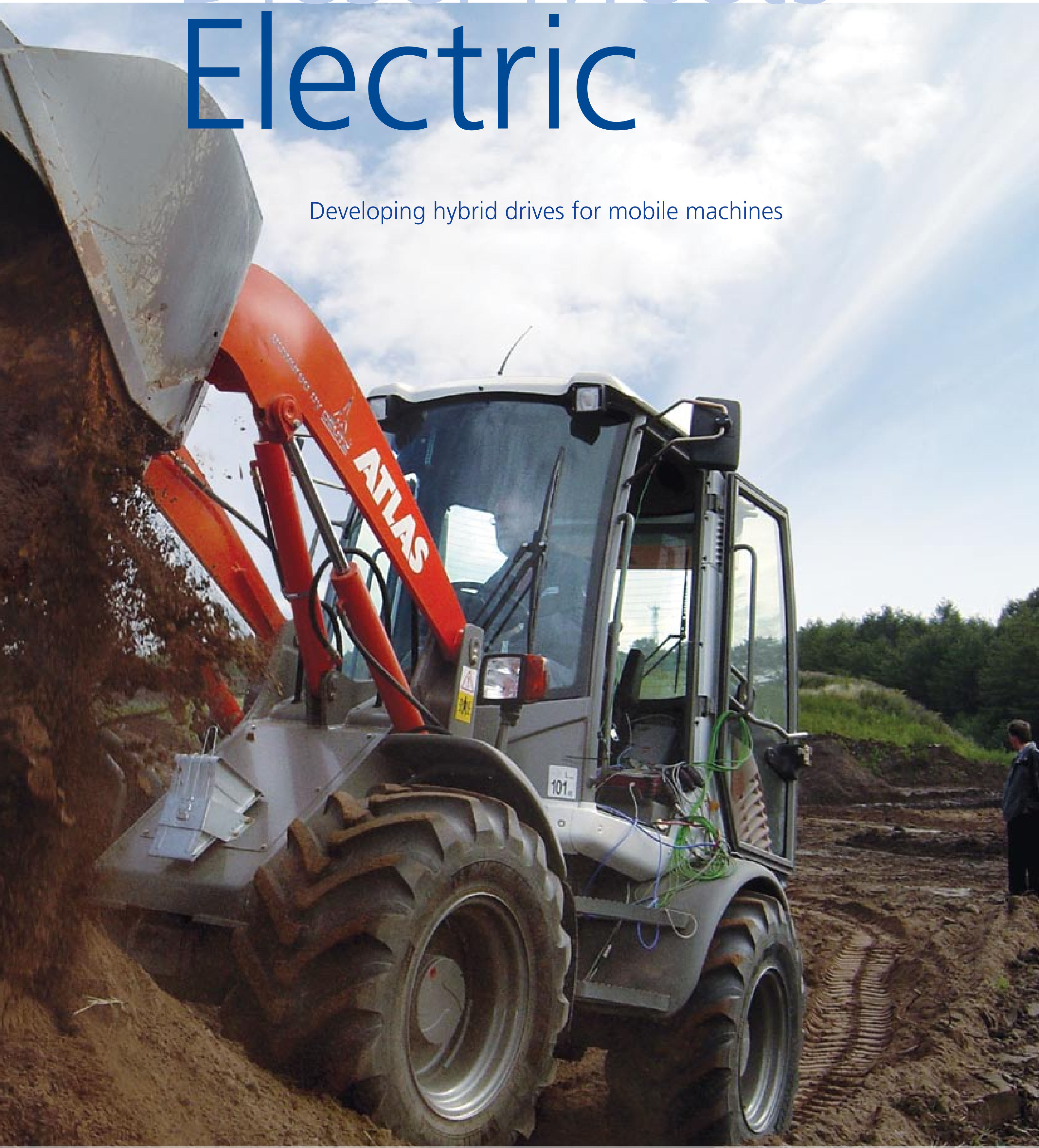
For years now, hybrid drives have been gaining ground in passenger cars. But mobile work machines, with their typical stop-and-go operation, are also ideal candidates for hybrid drives. Engine specialist Deutz and construction equipment manufacturer Atlas Weyhausen used dSPACE tools to develop a wheel loader with a hybrid drive. This carries a lot of advantages over a pure diesel engine.

Diesel Meets Electric

Developing hybrid drives for mobile machines



Why Hybrid?

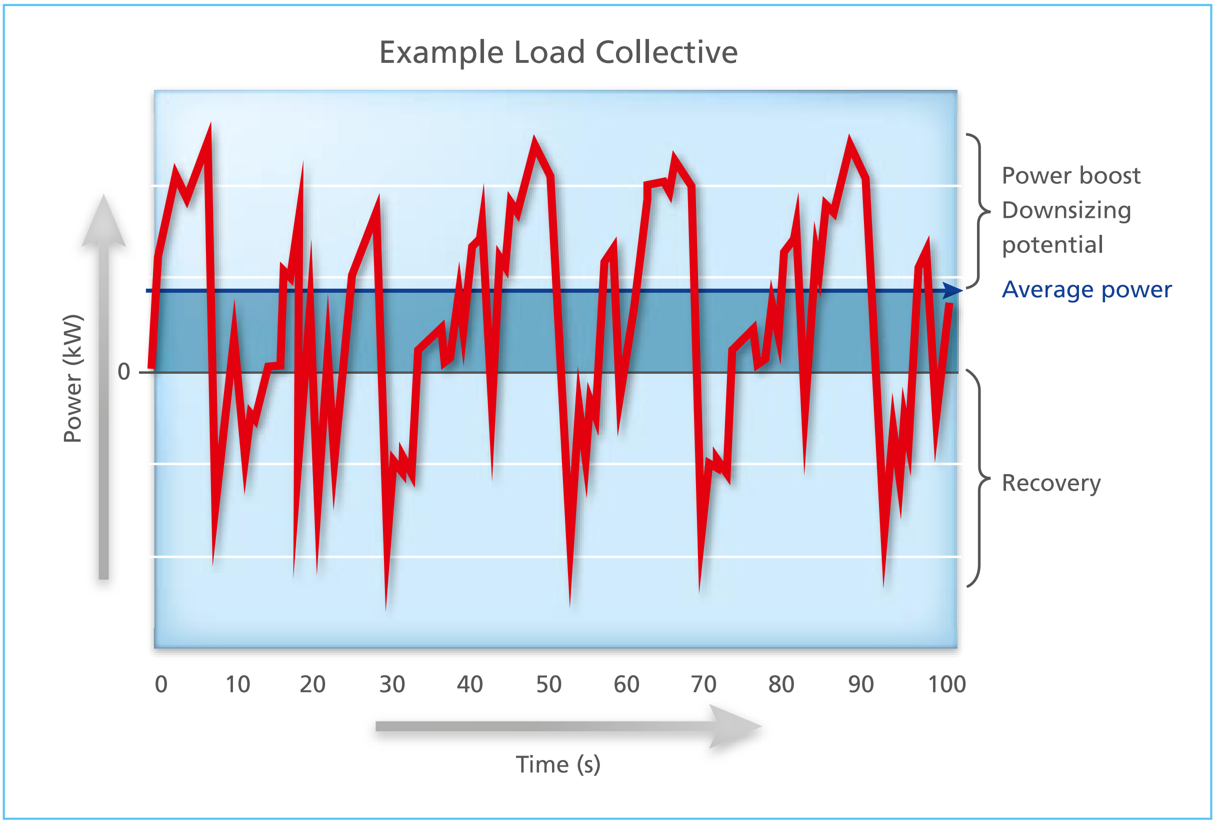
Most of today's hybrid drives are a combination of an engine and an electric motor. The electric motor plays a dual role: On the one hand, it is a generator that stores the energy that would otherwise be dissipated as heat when the vehicle brakes. On the other, it supports the engine at inefficient operating points, for example, when the vehicle starts up or when engine speeds are low. Unlike combustion engines, electric motors can reach high torques in these situations. These advantages mean that when used with suitable applications, hybrid drives have greater system efficiency, which in turn means lower CO_2 emissions and fuel consumption. In the face of rising fuel prices and stricter emission laws, hybrid drives are becoming more popular for this very reason.

Off-Road Benefits

Hybrid drives can really show their strength in any vehicle with frequent acceleration and braking, because this produces a lot of braking energy that can be recovered. These do not have to be on-road vehicles: excavators, loaders, and forklift trucks are all obvious candidates. What these off-roaders have in common is that they brake and accelerate frequently, travel very short distances, and have high load peaks – ideal conditions for using hybrid drives. They also have idling phases in which the motor can be switched on and off automatically to save even more fuel.

Wheel Loader with Hybrid Drive

In a joint project with wheel loader specialist Atlas Weyhausen, we used dSPACE tools to develop what is called a "mild" hybrid system for their AR-65 Super wheel loader. "Mild" means that the electric motor is rigidly coupled to the diesel engine and supports frequent braking and acceleration. This distinguishes mild hybrids from micro hybrids, which have only an automatic start-stop function, and from full hybrids, which allow pure electric driving. Hybrids have great potential for saving fuel by:



Load curve of a mobile machine. A fast sequence of braking, accelerating, and idling phases is typical – and ideal for hybrid drives.

Overview of the Implemented Hybrid Functions

- **Power Boost**
  Electric motor switched in when power peaks occur
- **Raising/Shifting the Load Point**
  Diesel engine operating point shifted to a range with higher efficiency
- **Start/Stop**
  Engine switched on/off during idle phases
- **Energy Recovery**
  Excess energy stored in Li-ion battery

The implemented functions provide a total fuel saving of 20 %, and CO_2 emissions are also reduced.

> "The RTI CAN MultiMessage Blockset meant we could set up the entire CAN communication system quickly and conveniently."
>
> *Marco Brun, Deutz AG*

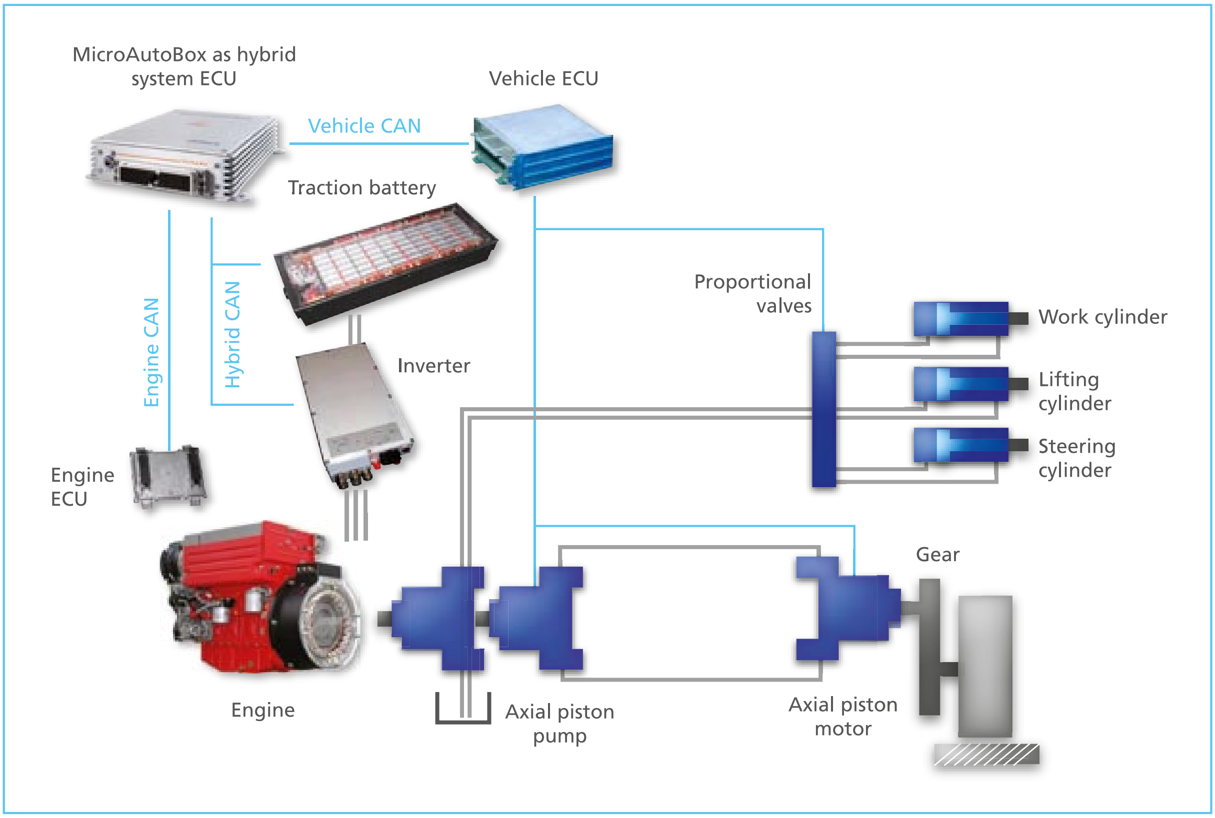
- Downsizing the diesel engine (using a diesel engine with less power, made possible by the added electric motor)
- Raising and shifting the load point (running the diesel engine in ranges with optimum efficiency)
- Energy recovery (storing braking energy in the battery)
- Start-stop (automatically switching off the engine during idle phases)

System Design

First of all, the wheel loader is driven by a DEUTZ three-cylinder diesel engine that delivers 36.9 kW at an engine speed of 2100 min^{-1}. Secondly, the powertrain is equipped with a constantly excited synchronous machine that has a rated and a peak output of 15 and 30 kW respectively and is integrated into the flywheel bell housing of the diesel engine. The rotor is directly coupled to the crankshaft. This form of integration meant that it was no problem to install the hybrid drive mechanically, as the electric machine requires hardly any additional space.
The hybrid system's traction battery is a lithium ion battery with a rated voltage of 400 V that is connected to the electric machine via a inverter. The inverter is responsible for commutating the synchronous machine and regulating torque by means of field-oriented control.
The hybrid drive is connected to two hydraulic pumps, the traction pump and the work pump. Like the hydraulic traction motor, the traction pump is designed as an axial piston machine. It is responsible for generating the hydraulic volume flow for the traction motor. This is called a hydrostatic traction drive – there is no mechanical gearbox anywhere in sight. The work pump sends the hydraulic oil through proportional valves to the hydraulic cylinders used to raise the bucket and steer the wheel loader.

Development with dSPACE Hardware and Software

We used several dSPACE tools to develop the software functions for the hybrid system's ECU:



Schematic of the mild hybrid system in the wheel loader. The MicroAutoBox is used as a superordinate hybrid system ECU.

- MicroAutoBox (as hybrid system ECU)
- Real-Time Interface (for setting up the I/O interfaces for the MicroAutoBox)
- RTI CAN MultiMessage Blockset (for setting up CAN communication)
- ControlDesk and CalDesk (for calibrating the hybrid functions)

By using RTI and the RTI CAN MultiMessage Blockset, we were able to implement fully functioning system software on the MicroAutoBox in only 3 months. The RTI CAN MultiMessage Blockset proved to be a very easy-to-use tool, and its support for linking CAN configuration files (DBC files) enabled us to set up the CAN communication very quickly.

Three CAN channels were set up in the wheel loader: engine CAN, hybrid CAN, and vehicle CAN. Because we programmed the system software directly in Simulink, we were able to try out the software functions immediately on a plant model (MIL) containing the engine, electric machine, inverter, battery, work hydraulics and traction hydraulics components. We were therefore able to test the software functions long before the first prototype components became available. This was absolutely essential in view of the very short development time assigned to this project.

Using the pretested software functions and the inputs and outputs configured with RTI (digital, analog, PWM, CAN), we produced a software version that would run on the MicroAutoBox and tested it on the test bench. Functions such as start/stop were tested and calibrated by means of ControlDesk and CalDesk.
Finally, we put the wheel loader into operation with the MicroAutoBox as a superordinate hybrid system ECU and implemented the functions for boosting power and raising/shifting the load point.

Cutting Emissions and Costs

By reducing fuel consumption, the hybrid drive not only lowers CO_2

emissions, it also results in considerable cost savings. An example calculation illustrates this clearly: Starting with a 20 % reduction in fuel consumption (and assuming that fuel consumption was previously 6.5 l / hour and that diesel costs € 1.30), € 1.70 per hour will be saved on a typical working day, or € 1500 in a year. The total savings for the entire working life of a wheel loader would more than offset the higher price of acquisition for the hybrid drive.

Production Status in 2010

With these obvious benefits in terms of emission and cost reduction, we see great potential for hybrid drives in the field of mobile work machines. So as our next step, we will employ further wheel loaders and construction equipment wheel loaders – each equipped with a dSPACE MicroAutoBox – at various customers to gather experience in everyday use. Our aim is to bring this hybrid system up to production status by mid-2010.

Marco Brun
Deutz AG
Germany

Externally, the only part that differs from the standard wheel loader is the roof-mounted lithium ion battery.

Developing the Software Functions with Model-in-the-Loop

- Modeling the diesel engine, ECU, inverter, electric motor and BMS (battery management system)
- Setting up the hybrid software functions followed by MIL test Setting up the I/O and CAN interfaces
- Testing communication in ECU network

Commissioning the Hybrid System on the Test Bench

- Setting up the diesel engine, electric motor, inverter, Li-ion battery, hybrid ECU
- Implementing the safety functions
- Implementing the ECU network
- Testing and preadjusting the hybrid functions

Implementing and Calibrating the Functions in the Wheel Loader

- Calibrating repeat start when wheel moved or gas pedal/inch pedal/joystick touched
- Calibrating the power boost function, load point shift and energy recovery

The workflow for developing the hybrid software functions. Fully functioning system software was implemented on the dSPACE MicroAutoBox in the wheel loader after only 3 months.