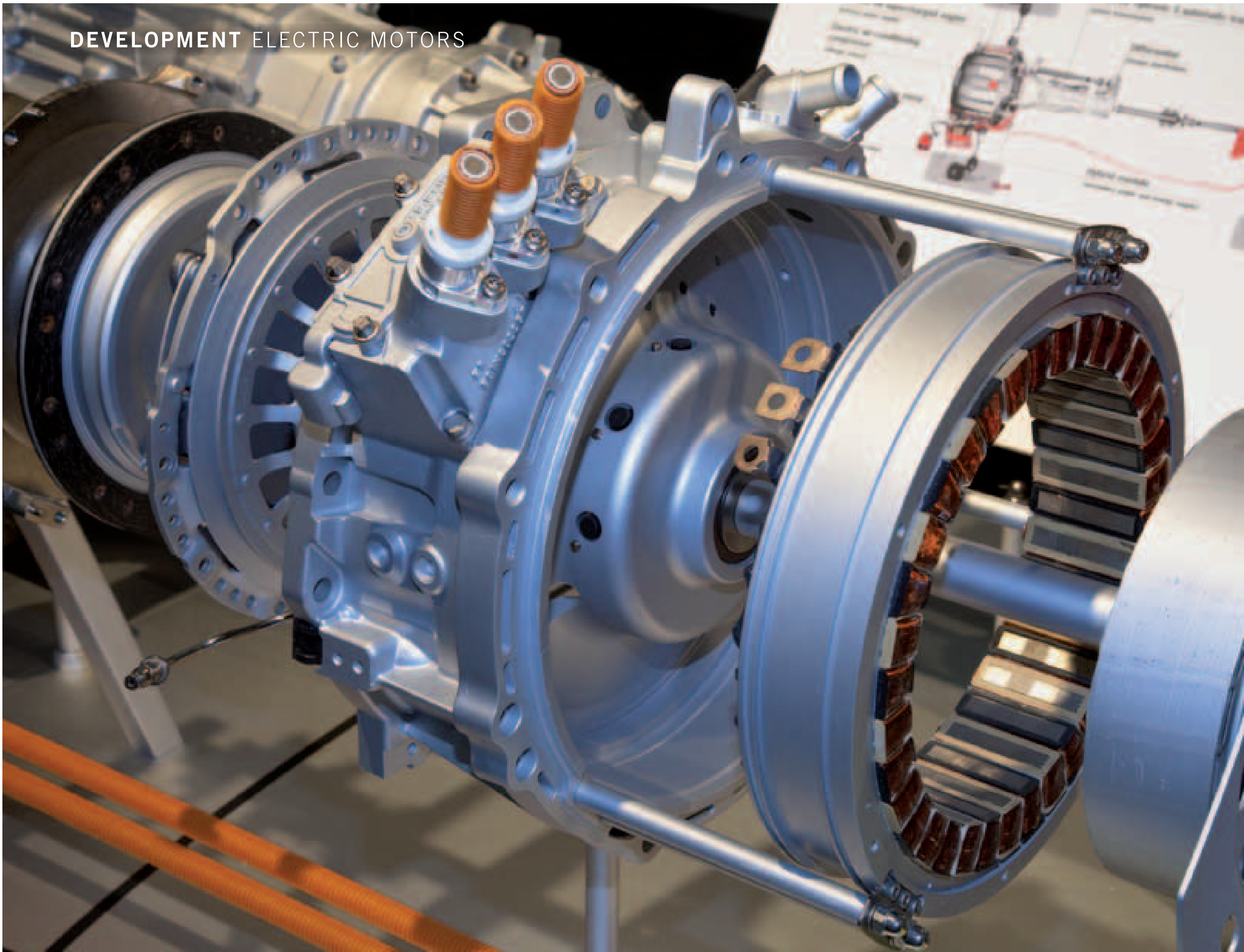


ELECTRIC MOTOR EMULATOR VERSUS ROTATING TEST RIG

A controversial issue among experts is whether real-time model-based electric motor emulation can replace a conventional rotating test rig with a load machine. For the first time, an OEM from Southern Germany used a complete inverter test system with an integrated electric motor emulator from SET GmbH to develop hybrid drive trains. In particular, the emulator's mapping accurancy is investigated.

AUTHORS

DIPL.-ING. (FH) HORST HAMMERER
is a Member of the Executive of the SET GmbH in Wangen (Germany).

DIPL.-ING. (FH) DIETER STRAUSS
is a freelance copywriter for technology issues in Olching (Germany).

TOOLS FOR ECU DEVELOPMENT

Techniques such as model-in-the-loop (MIL) and software-in-the-loop (SiL) represent the state-of-the-art in developing torque control units for electric motors in hybrid drivetrains. Once prototyped in hardware, controllers are usually tested on a hardware-in-the-loop (HiL) test rig. Real-life control logic and control devices are already available, whereas the electric motor is only simulated with high-voltage power electronics still lacking at this stage. Load currents are calculated from the HiL test rig, and the corresponding controller parameters are set.

CONVENTIONAL ECU TESTING WITH AN ELECTRIC MOTOR AND DYNAMOMETER

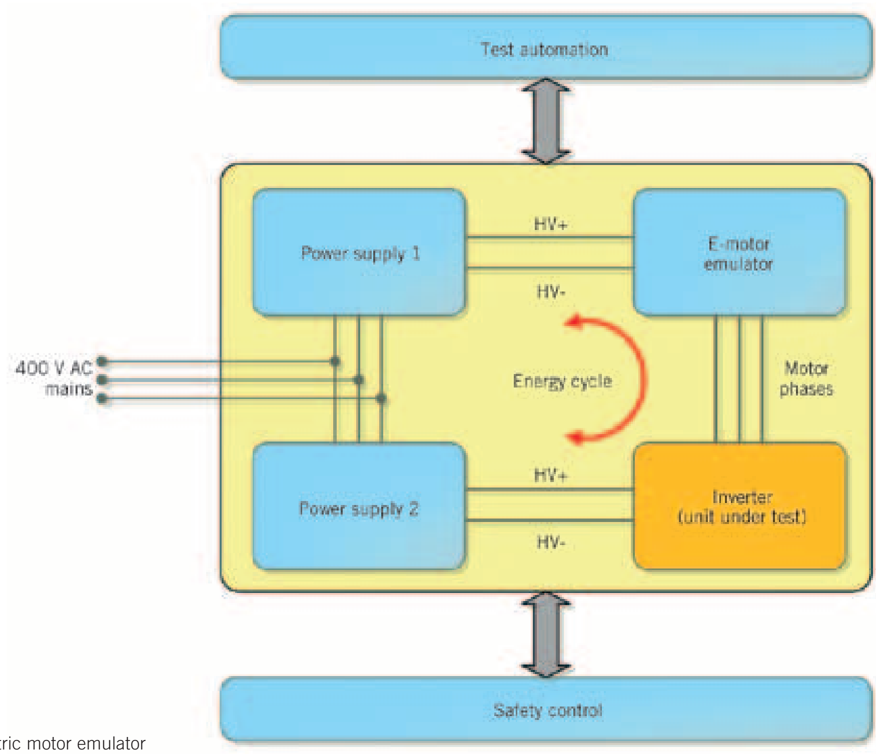
A load test rig is usually used in the next step; in the simplest case, the original electric motor in the hybrid drivetrain is coupled to another controlled electric motor. This electric motor-dynamometer configuration involves a real-life electric drive tested together with a real-life controller that already includes high-voltage power electronics at this stage in testing.

The problem with this procedure is that the rotating test rig itself constitutes a drivetrain with drive shafts and load machine, but has nothing in common with the vehicle the electric motor will eventually be installed into, rendering it almost impossible to model mechanical feedback and turning-speed dynamics from the vehicle to any level of accuracy. This is a serious disadvantage since electric motor speed is not always coupled to vehicle speed – especially in hybrid drives; there are intermediate states with gears disengaged and no drive to the wheels, suddenly leaving the electric motor to turn without any load. None of the resulting turning speed dynamics can be reproduced in a rotating test rig since the inert masses involved are too far from those in the future vehicle, so the ECU had to be tested and configured in a test vehicle on the road. The complete inverter test system from SET GmbH, Wangen (Germany), ❶, bridges this gap between the HIL test rig and vehicle testing. This system allows load and ambient conditions to be reproduced in the lab exactly as they occur in a drive inverter during a real-life driving situation; consistent front-loading of everything from road tests to component tests on the test rig reduces costs and minimises development cycles while yielding test data of higher quality.

ELECTRIC MOTOR EMULATOR TESTING

The electric motor emulator with its two-quadrant high-voltage DC supply forms the central component in the new solution, ❷. Two power supplies are available – one for the electric motor emulator and

❶ Operation of an inverter on the test system from SET



❷ Complete inverter test system with an integrated electric motor emulator

one for the sample motor for the ECU to be tested at different voltages, allowing voltage fluctuation simulation in the high-voltage battery supply. The energy loop is closed via the power supplies. A safety and a test automation control complete the system.

The electric motor emulator is a model-based simulation of the electric motor to be controlled by an ECU consisting of a controller, logic control and inverter. Any electric motor can be software-emulated using this modelling principle. The test operator specifies the electrical and mechanical specifications of the specific electric motor such as impedance, number of pole pairs, magnetic flux, inert mass, friction and so on using the GUI.

Non-linearities and varying dependencies in magnetic flux can also be mapped for a virtual electric motor that remains true to real-life conditions even in extreme operating conditions, such as field weakening. In field-weakening operation, the inverter not only sets up torque-phase current (Iq), but also a field-weakening share of the current (Id) to weaken the field on the permanent magnet and reduce the back-EMF in the electric motor. Proper field-weakening emulation is essential for modelling operating points at high turning speeds and determining increased losses in the test motor's inverter at constant motor performance and decreasing torque.

Other test system components are designed on the strength of performance data from the motor to be emulated; these components include power supplies for the test object – in this case, the ECU with controller and inverter, test mount and cooling system. Emulators can test for heavy currents, unlike simulators; a reliable cooling system is needed for the power electronics required by the emulator. A computer with integrated features ensuring operational safety rounds off the test system.

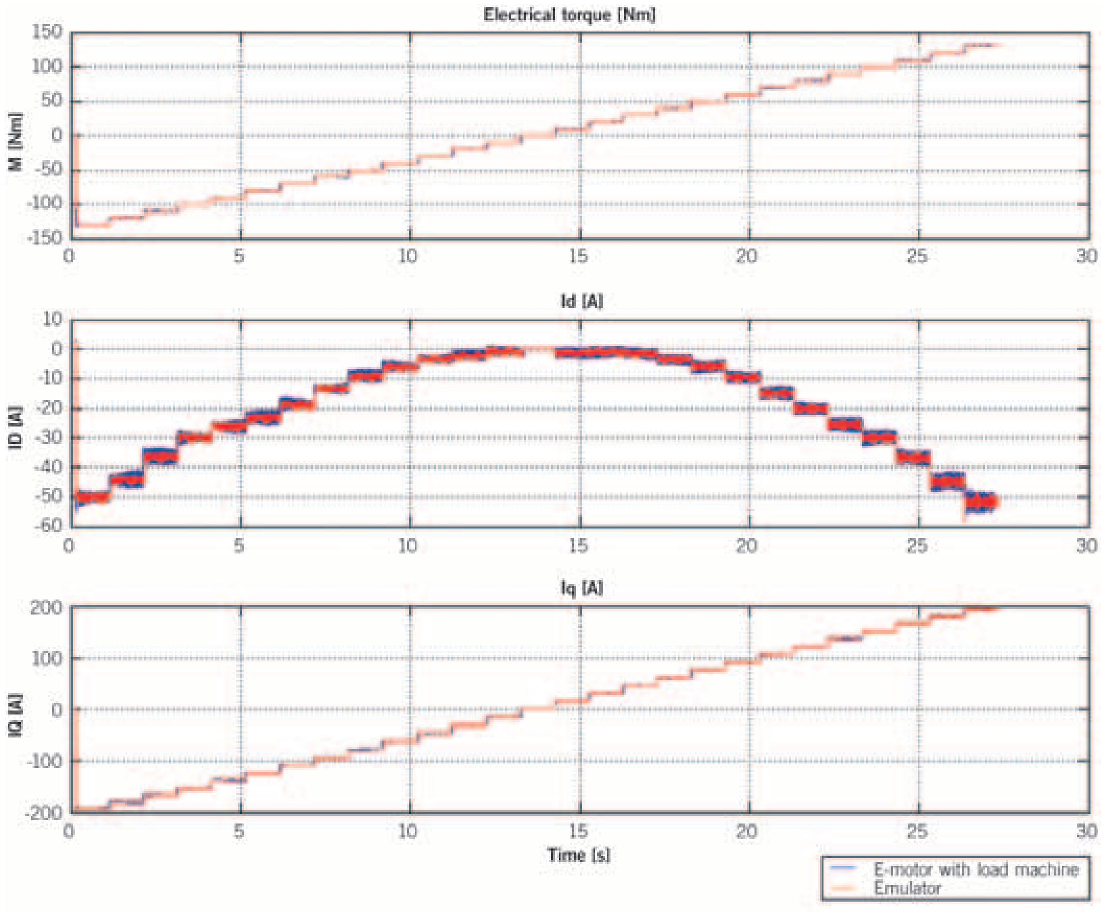
PRECISE MAPPING FOR A REAL ELECTRIC MOTOR

The first tests after commissioning involved examining whether the electric motor emulator behaved like a rotating test rig. The electric motor's static and dynamic characteristics was determined by measurement on a load test rig. Data recorded included current, acceleration and voltages transformed. The next step involved entering the data from the electric motor – such as flux and torque constants, inert mass, impedance, friction – into the emulator, and performing the same tests as on the load test rig. Comparison between measurement plots, ❸ and ❹ shows congruence between emulator and load test rig data, so the emulator behaves like the real motor rather than giving a rough approximation.

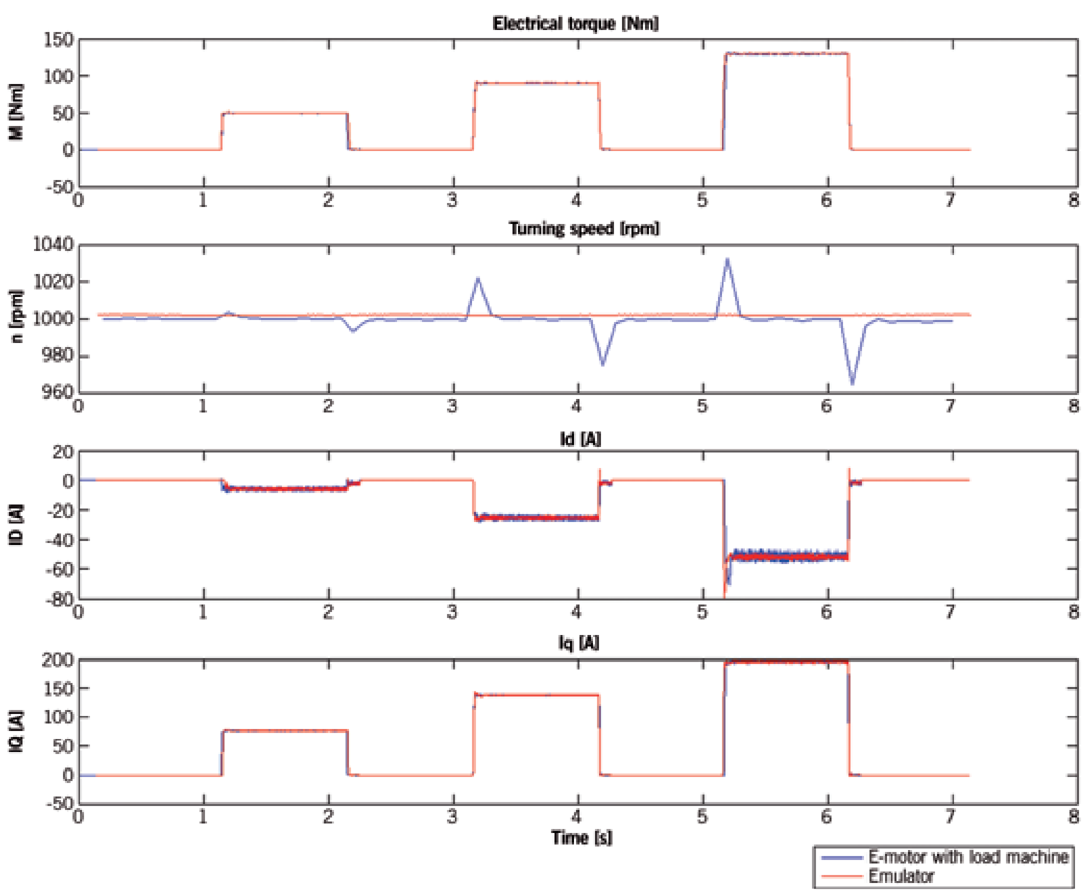
The emulator also behaves as a real-life electric motor would in dynamic operation; in contrast, the rotating test rig deviates from the expected values, ④, due to the dynamometer's inertia and limited dynamic response, and is only limited in its suitability for mapping the electric motor's dynamic speed behaviour. As an example, a real-life electric motor has nonlinearities that lead to harmonics in the torque curve; since these harmonics are caused by nonlinearities in the electric motor, parameters such as magnetic characteristics in the rotor and stator are only approximately linear. A complete inverter test system makes it possible to study harmonic behaviour and potential technical control strategies with accuracy, ❺.

ADVANTAGES OF THE EMULATOR SOLUTION

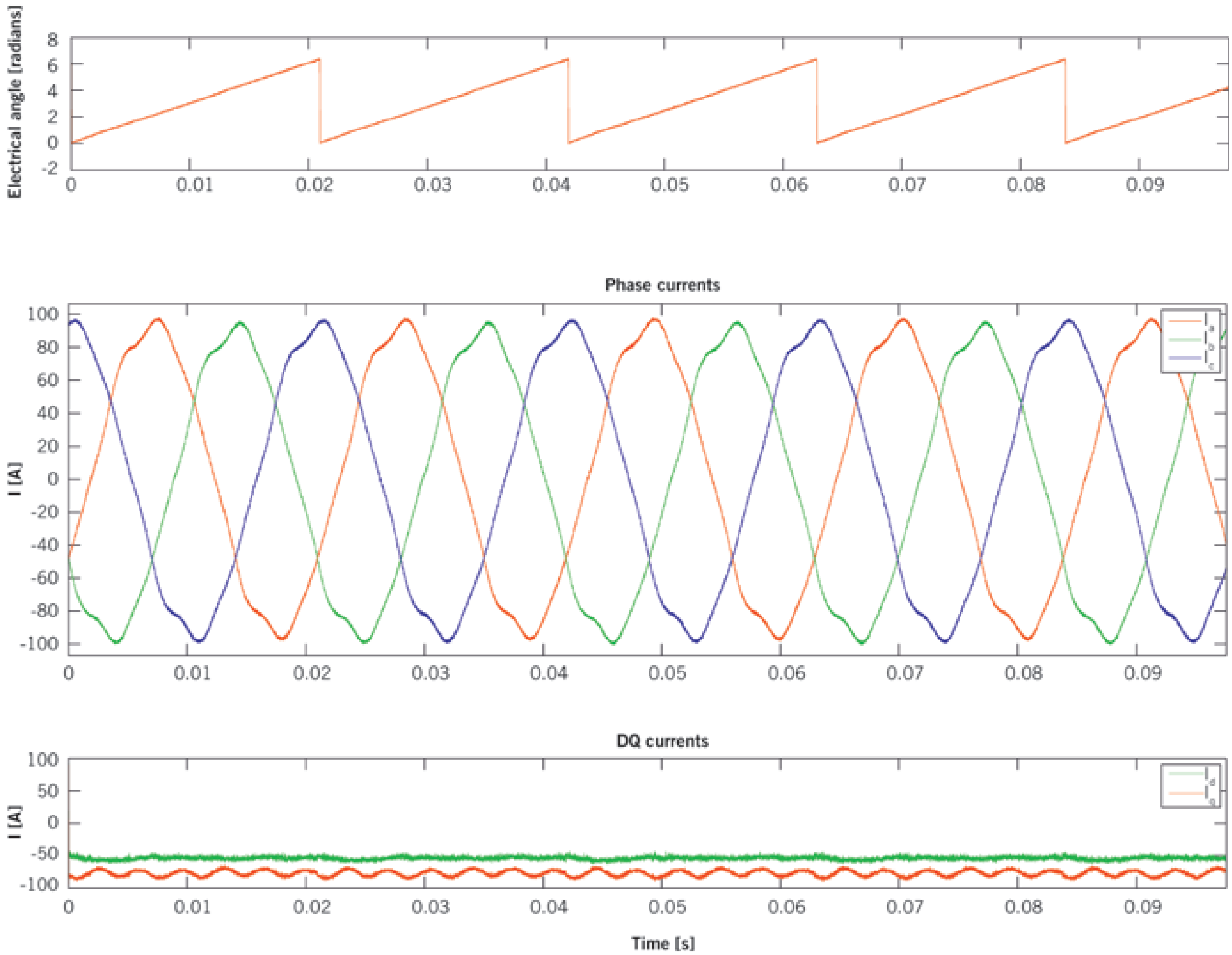
The complete inverter test system supports electric motor and controller devel-



❸ The complete inverter test system in static operation behaves like a load test rig, but without compromising on turning-speed dynamics; for comparison, a torque-ramp has been run through at a fixed speed on a test rig with a real load machine and on an inverter test system; the measurement plots has been superimposed



❹ In the second series of measurements, the torque has been changed abruptly; here, the high dynamics of the emulator compared to the load machine becomes obvious, the load machine causes undesirable speed fluctuations



5 Effect of harmonics on torque – torque-generating phase current (Iq) produces 300 Hz torque modulation caused by the fifth and seventh harmonics simulated; a load test rig cannot model this dynamic behaviour

opment in a parallel process – while one development team designs the electric motor, another team can construct a prototype of the controller and perform initial tests on the electric motor emulator. After deriving parameters from the electric motor design specification using FEM analysis tools and entering the parameters into the emulator, the developer team can conduct preliminary controller tests before the electric motor even comes into existence. The key advantage here is that the test results are ready for use in optimising the electric motor's design at this early stage.

Another advantage applies to the power electronics – realistic load tests for power electronics can run automatically day and night using real-world driving profiles taken from test vehicles.

The most important advantage lies in the emulation solution's complete model-based vehicle drivetrain mapping together with its inherent vibration behaviour. Dynamometers are subject to an inherently narrow turning-speed range of a few hertz under these conditions, whereas the emulator's extreme dynamics can accurately map vibration allowing realistic and reproducible testing for the corresponding attenuation algorithms in the inverter software in lab conditions.

CONCLUSIONS AND RECOMMENDATIONS

The SET complete inverter system can be used at very early stages in developing and testing hybrid drives and other drives with electric motors. Any electric motor type can be mapped using an integrated emulator; compared to rotating test rigs, an emulator will behave like the corresponding real-life electric motor in dynamic turning-speed operation. In addition, emulators allow developers to model phenomena not yet accounted for in controllers – phenomena such as harmonic vibrations in electric motors and cancelling out acoustic effects in control engineering.

Besides development testing of inverters for electric motors, the test system can be used for other tasks such as system testing and end-of-line testing. The benefit of this system is – from the perspective of the inverter under test – that it runs like a real electric motor, but without any moving parts.

ATZ. A VARIETY IN AUTOMOTIVE KNOWLEDGE.

6 TITLES WITH TOPICS FOR EVERY DISCIPLINE.

Up-to-date information, printed and digital formats, advanced training and events: this is **ATZ**. Professional journals for every discipline within the automotive world, with additional digital features like **ATZ online** portal and eMagazines. Plus events, conferences and seminars. One publisher, every bit of information.

See the entire collection at *www.ATZonline.com*

ATZ