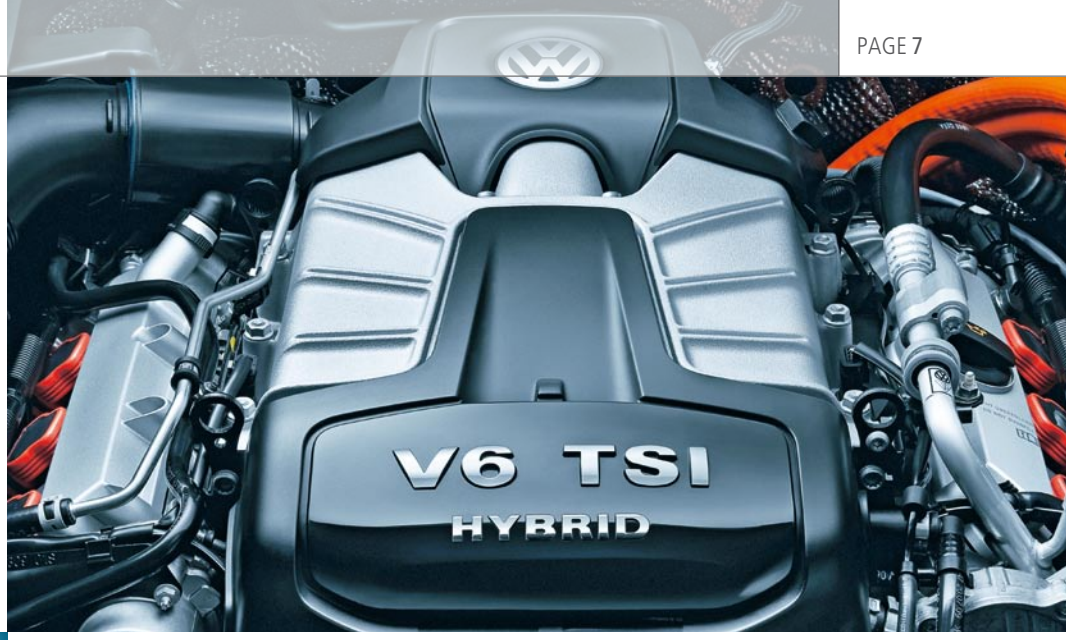
Touareg Hybrid – electrified and electrifying

Function integration test for a hybridized powertrain at Volkswagen: There's power in teamwork!



The Volkswagen Touareg has a brand-new hybrid version. Its electric drives, power electronics, and traction battery have caused a significant rise in the complexity of the networked electronic systems. From function development to electronic control unit (ECU) release tests, Volkswagen systematically relies on hardware-in-the-loop (HIL) simulation for functionality verification and quality assurance.

The New Volkswagen Touareg

When it was launched, the Volkswagen Touareg immediately set new standards in comfort and safety with its innovative vehicle functions: such adaptive cruise control (ACC), Side Assist (lane-departure warning), and Rear Assist (parking camera), to name just a few.

The new version of the Touareg continues the company's policy of bringing customer-friendly innovations up to production level and then using them throughout its entire vehicle range. For the very first time, the Volkswagen Touareg is now available with a hybrid powertrain (figure 1) as well as further-developed assistance systems such as a pre-crash system that evaluates data from radar and video sensors.

The full-hybrid powertrain makes tough demands on function and ECU networking. This means that the OEM needs optimal system integration. The OEM is responsible for the final vehicle and has to ensure that all its systems, including ones from different suppliers, are error-free and robust when they run in the overall vehicle.

Reasons for Using a HIL Test Bench

The decision to create a networked hardware-in-the-loop (HIL) test environment resulted from two primary requirements:

- The integration testing of networked ECU functions, especially the hybrid functions, must be set up quickly and dynamically.

- Because only a limited number of prototypes is available in early development phases, there must be a test station that suppliers and specialist departments can use for function development and special tests during development.

Choosing the HIL Test Bench

For the first time ever, Volkswagen used a networked HIL simulator to test a hybrid powertrain, with the Touareg Hybrid as the first case this was used for. This called for a strong partner with comprehensive experience in ECUs and simulating electric drive components, and Volkswagen chose dSPACE. Especially in the early test phases in the development process, ECUs are not fully functioning and diagnostics-capable yet, which makes it difficult to put them into operation on the simulator. This is where dSPACE's experience as a HIL development partner comes into play. Their competence in new, innovative bus systems such as FlexRay was the final decisive factor in choosing them as a testing partner.

Volkswagen's Integration Testing and Test Case Creation Process

To handle the complexity of the driver assistance functions distributed throughout the entire vehicle, Volkswagen not only works on real vehicles and test benches, but also systematically uses hardware-in-the-loop simulation. In a multistage testing process, at fixed points in time during the product creation process (PCP) the vehicle's overall status is studied on the integration HIL test bench. These tests are part of overall integration testing. This makes it possible to investigate and verify the interactions between the systems and the external effects of their functions at a high level of test coverage in early development phases.

To determine the vehicle's current maturity with respect to system integration, different test locations such as prototype vehicles or test benches are used during overall integration testing, depending on the test task. The test results from these are bundled and consolidated to provide detailed monitoring of the vehicle's overall integration status. The test locations for specific tests are selected from the available electronics testing facilities (figure 2) according to their suitability and availability.

The ECU tests performed on the HIL test bench focus on selected testing issues (table 1). The HIL tests also support the systematic analysis of any irregularities that emerge from test drives. Thus, the HIL test systems

Figure 1: The hybridized powertrain including the battery module of the Touareg.

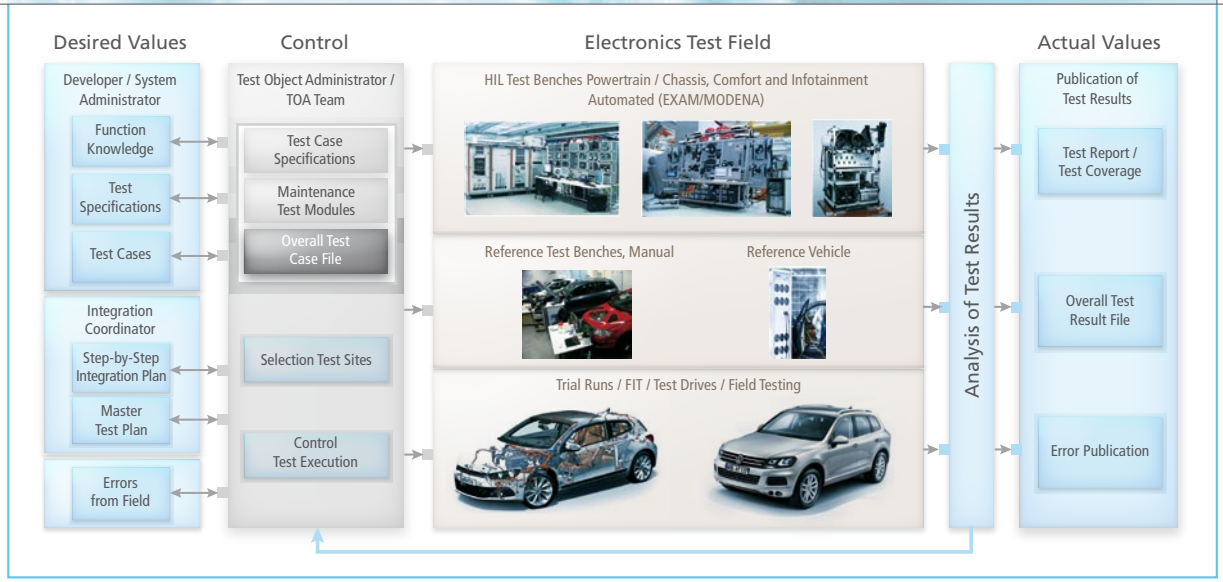


Figure 2: Structure of the electronics testing facilities.

provide considerable technical added value and are used efficiently in the development and release process.

Requirements for the Test System

The basic requirement for the test environment is the HIL test station's ability to represent all the networked ECU functions that are experienced by customers: for example, when the ECU in the vehicle receives data from sensors and actuators, it must respond without any errors. The networked HIL simulator for the Touareg Hybrid is extremely complex, with 29 ECUs. To handle this complexity, the test bench supplier has to fulfill numerous requirements when commissioning and operating the test bench:

> "Without such good cooperation with the ECU developers, it would not have been possible to put the test bench into operation."
>
> *René Schüler, Volkswagen AG*

Modularity

Initially, the test station must be designed for three motor variants and the automatic transmission of the Volkswagen Touareg, and be able to switch between them quickly: diesel (3.0 l TDI), gasoline (3.6 l FSI) and hybrid (3.0 l KFSI).

Flexibility

Volkswagen begins HIL testing with the first prototype two years before start of production (SOP). At that point in time, the ECUs are still being developed and subject to system modifications such as sensor adjustments and changes in the plug connectors' pinouts. These changes need to be made on the HIL simulator quickly and smoothly – and usually despite a lack of mature ECU diagnostics.

Table 1: Test issues for HIL testing.

Test Issue	Description
Hybrid ready status	Conditions on which the hybrid must achieve ready status and conditions on which ready status must be prevented.
Coordination of operating states	Conditions for individual operating states such as starting/stopping the combustion engine, electric operation, braking/recuperation, boost function, (charging by generator), transition states.
Driver information and controls for the hybrid	Information on the hybrid given to the driver via instrument cluster and display, energy flow display, onboard computer, recuperation display, warning signals, error messages.
Error responses and substitute measures	Testing the ECU's desired reactions to inserted failure states.

The NiMH battery is installed in the rear.

> "Answers to questions on functions and the development status of the ECU were usually just a phone call away. And the responsible developer, with all the necessary knowledge, was on hand immediately."
>
> *Christian Claus, IAV GmbH*

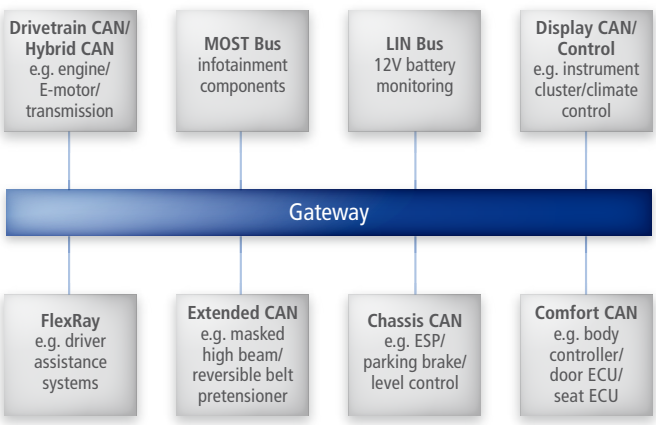
Efficient Software Structures and System Stability

The network simulator used by Volkswagen contributes greatly to function testing and software version release. Any system used for this has to function stably – especially in automated testing. Frequent changes to the drive variants make this more difficult.

User-Friendliness

Not every test bench user must be trained to be a HIL expert. The engineers responsible for specific test objects and the specialist departments/suppliers use the HIL simulator to perform their test tasks efficiently. Efficiency means concentrating on ECU functions without having to acquire in-depth simulator knowledge.

Figure 3: The networking architecture of the Touareg Hybrid.



Structure of the Network Simulator

The simulator for the Touareg Hybrid is designed as a virtual vehicle and covers all vehicle domains. The powertrain comprises the following systems:

- Combustion engine
- Electric motor
- Transmission
- High-voltage battery

These systems are simulated realistically by simulation models, various real parts such as a throttle and injection valves, and high-voltage electronics that emulate the battery voltage.

The HIL system can be configured for three different motor variants and an automatic transmission with different gear ratios and converters. The motor and transmission variants are identified by means of ECU-specific mapping connectors. Finally, the associated model parameters are loaded. This achieves the necessary modularity and flexibility.

For the most part, the ECUs under test are on a test bench setup that was provided by Volkswagen's test setup service (figure 4).

Bus Systems

The powertrain domain is equipped with various CAN and LIN buses and a FlexRay bus (figure 3). Restbus simulations were set up for all the buses. The CAN buses have a manipulation gateway for main switching and

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local switching. This makes it possible to take each single ECU off the bus and isolate it on a separate bus. The messages received on one bus can be mirrored on the other. This switching method makes it possible to manipulate targeted CAN messages or even delay them at signal level, and also to simulate an ECU failure.

Simulation Models

VW's own simulation models for the combustion engines and dSPACE's Automotive Simulation Models (ASM) are used. The hybrid powertrain and the vehicle dynamics are simulated with ASM DriveTrain, ASM Electric Components and ASM Vehicle Dynamics. Because of their open structure, the ASMs were easy to combine with the VW models to create an overall model for the hybrid powertrain. A spindle actuator implemented in the drivetrain model is used to decouple the combustion engine in order to simulate purely electric operation. A battery model from ASM Electric Components is parameterized for nickel metal hydride (NiMH) characteristics and is used for the high-voltage battery. The models have proven to be very robust and enable the simulation of all conventional and hybrid operating conditions such as purely electric driving, hybrid driving, combustion engine driving, recuperation, and coasting. The open models meet the requirements for efficient software structure.

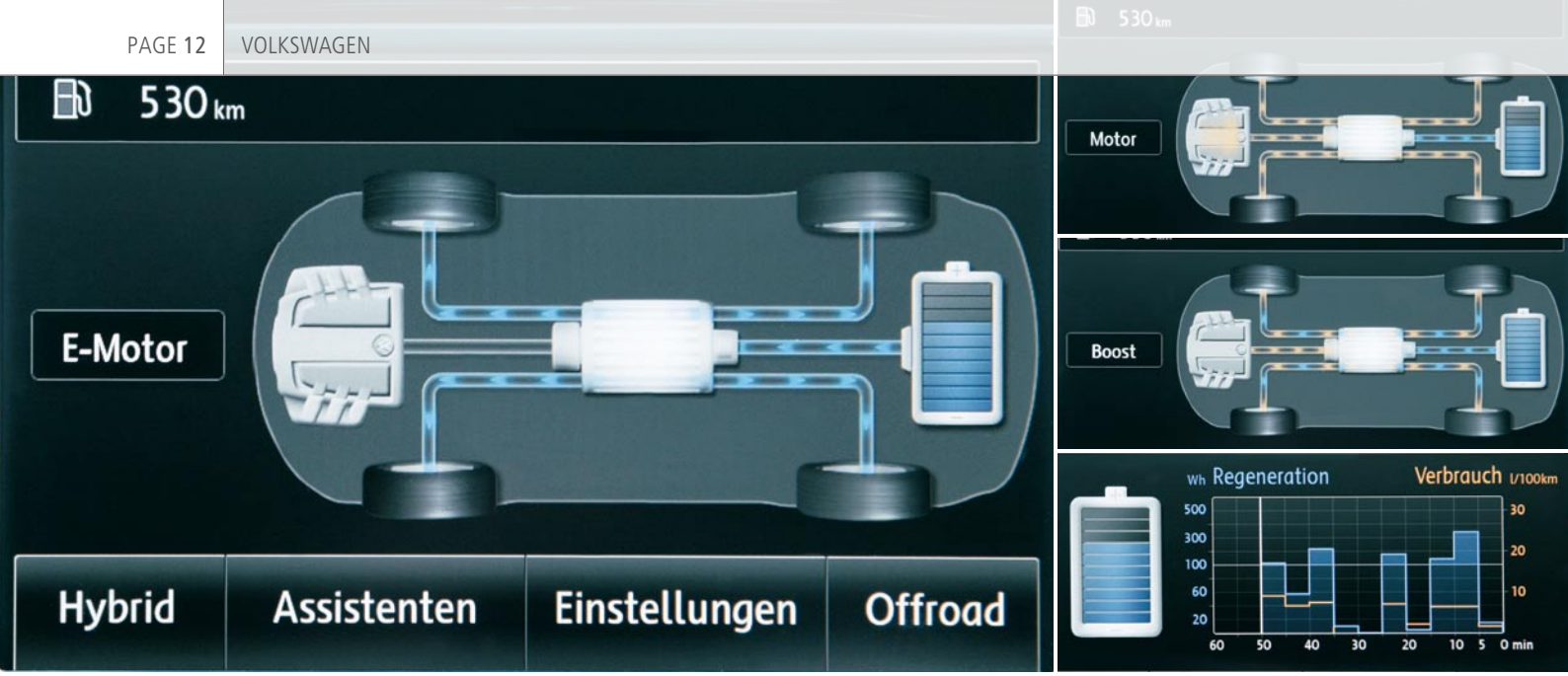
Battery Simulation and Emulation

To test the battery management system (BMS), the high-voltage battery's terminal voltage and the voltages of the battery cell clusters have to be emulated. A controllable 400-volt power supply and several galvanically isolated DC amplifiers are available for this. The simulation of cell and battery behavior uses the battery model from the ASM Electric Components, which controls the power supply and the amplifiers. This system provides reliable representation of the on/off currents, the charging and operating behavior of the NiMH energy store, etc. To isolate the high voltages and protect operating personnel, the high-voltage electronics are installed in the simulator as a sealed system.

Simulating the Electric Motor

The electric machine, which has an output of 38 kW in the Touareg, is simulated by a three-phase-current motor model from the ASM Electric Components. Evaluation at signal level is sufficient for testing the electric motor ECU. The interfaces between the signal and the output electronics were opened up physically for this. The pulse-width-modulated (PWM) signals to control the power electronics (IGBT) are measured with a PWM Measurement Solution and processed in the motor model. The model provides position and current signals that are passed to the ECU via interface boards (DS5202 PSS, DS2102). This means that the ECU can be tested in a closed control loop.

Figure 4: The simulator and the test setup in the laboratory.



Driver information display with energy flow indicators for purely electric driving, charging, boosting, and battery regeneration and fuel consumption.

Operation and Experience

Once again, the process of putting the simulator into operation showed that as vehicles become more complex, closer cooperation between testers, test bench operators and – most importantly – developers is essential. A project like this cannot be carried out without the know-how of ECU developers from the individual specialist departments and their readiness to support commissioning. The same applies to subsequent test bench operation, as this is the only way to quickly and efficiently carry out changes to the ECU software or hardware and the resulting changes in test bench requirements.

> "The Automotive Simulation Models (ASM) from dSPACE guarantee solid, reliable simulation of the Touareg Hybrid's electrical components."
>
> *René Schüler, Volkswagen AG*

In addition to the supporting developers, a resident engineer from dSPACE helped to make the modifications and to adapt the HIL simulator to new situations. There is always on-site support from HIL experts, and direct contact with dSPACE's development department is also guaranteed.

Because of the high dynamics and modularity of the test setup adaptations, it is always possible to run the current ECU versions in the integration test phases described above. In addition to checking the networked functions for ACC, Side Assist, ESP, etc., the test focused on hybrid coordination. This mainly concerned testing the driver information and the driver controls for the hybrid functions, along with correct responses to failures and plausible selection of driving states.

Outlook

Volkswagen plans to extend the HIL test bench for future Touareg motor

René Schüler, Volkswagen AG
René Schüler is Project Manager for HIL simulation for the Touareg Hybrid at Volkswagen in Wolfsburg, Germany.

Christian Claus, IAV GmbH
Christian Claus, a project engineer, was a significant contributor to the HIL testing of the Touareg Hybrid at Volkswagen.

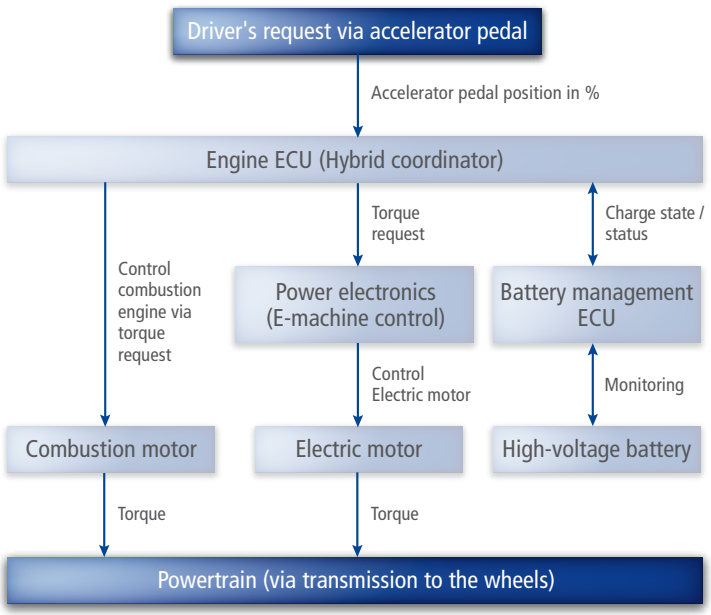
variants. This will involve integrating new combustion engine models and setting up ECU identification via mapping connectors. High resolution environment simulations for virtual test drives will also be added to the HIL test environment so that ECUs for advanced driver assistance systems (ADAS) can be included in simulation. The sensors (camera, radar) in these systems will have to be stimulated appropriately for this. ■

René Schüler,
Dr. Marcus Brand
Volkswagen AG
Christian Claus
IAV GmbH
Germany

Example of a Networked Function in the Touareg Hybrid

The engine ECU not only controls the combustion engine, it is also the hybrid coordinator. Its task is to coordinate the torques in the powertrain and to monitor the participating ECUs, such as for battery management and power electronics.

When the driver depresses the accelerator pedal, this tells the engine ECU the desired torque. The engine ECU uses this torque (desired acceleration/speed), and also the system status, the temperatures and the battery charge state (SOC), to decide whether to initiate electrical driving, combustion engine driving, or a combination of the two known as "boosting".



Conclusion

The dSPACE HIL simulator immensely helped during function verification when the Volkswagen Touareg was developed. Even after the initial start of production, the test station is being used for further versions and vehicle enhancements. Because setup times are very short, it was possible to test several motor variants in the integration testing phases. Working with dSPACE, we have discovered the requirements and challenges involved in the verification of networked hybrid functions on the HIL simulator. We will be putting this knowledge back into future projects. Volkswagen firmly believes in close cooperation between automotive brands to verify functions with networked HIL test benches. The successors to the Volkswagen Touareg, the Audi A8 and the Porsche Cayenne are based on modular longitudinal platform technology (MLP, also known as MLB). This led to the goal of using standardized HIL test bench equipment, ideally with a uniform hardware and software structure from standardized vehicle technology. One of the reasons for choosing dSPACE for MLP testing was dSPACE's extensive experience working with Audi (the leading MLP developer). Working together, Audi, Volkswagen and Porsche are planning, implementing and commissioning the test stations, utilizing all the synergies inherent in closely related vehicle projects. In addition to HIL technology, successful cooperation on test case creation, test case automation (the in-house tool EXAM) and error tracing has also evolved.