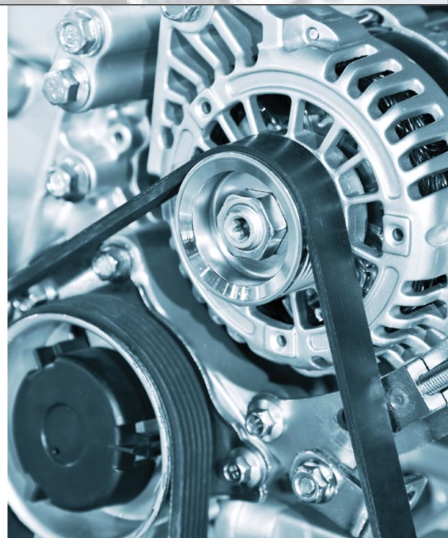
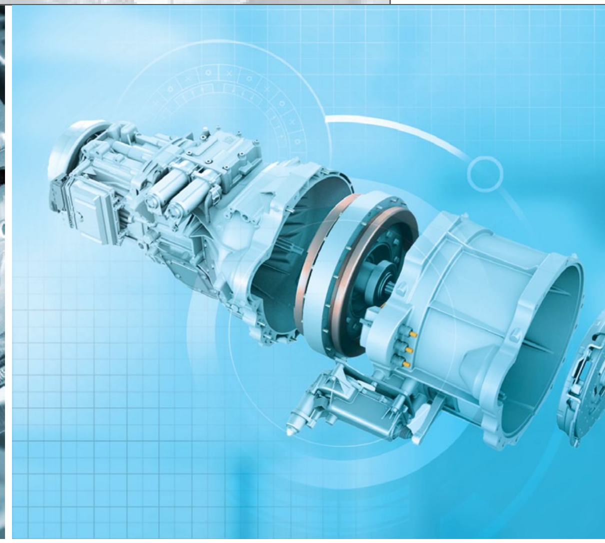
The new 48-volt vehicle electrical system is opening up new possibilities for powerful, cost-efficient hybrid drives. This leads to new challenges for validating the installed power electronics. To provide testing services for the automotive industry, the Korea Automotive Technology Institute (KATECH) is using a complete, flexible test system by dSPACE.

Validating ECUs of hybrid drivetrains at power level

Virtual Mild Hybrids


Example of a mild hybrid with a belt-driven starter generator.


Example of a hybrid approach that integrates the electric motor with the transmission input shaft.

The number of electrical consumers in vehicles is increasing steadily, causing the power consumption to rise as well. As a result, 12 V power supplies often reach their limits when supplying components that have high power requirements. The introduction of the 48 V system overcomes this bottleneck. It achieves the same, or even higher, performance level but at lower currents. To meet the requirements of 48 V systems, car manufacturers are redesigning electrical systems and their components, such as the batteries, converters and generators. Some leading OEMs have therefore agreed to incorporate a number of common architectural elements in their on-board power networks, including a 48 V battery unit, a charging port for all electric and hybrid vehicles, and CAN bus interfaces that support partial network operation. These technologies are a decisive basis for the further development of cost-effective, hybridized drivetrains.

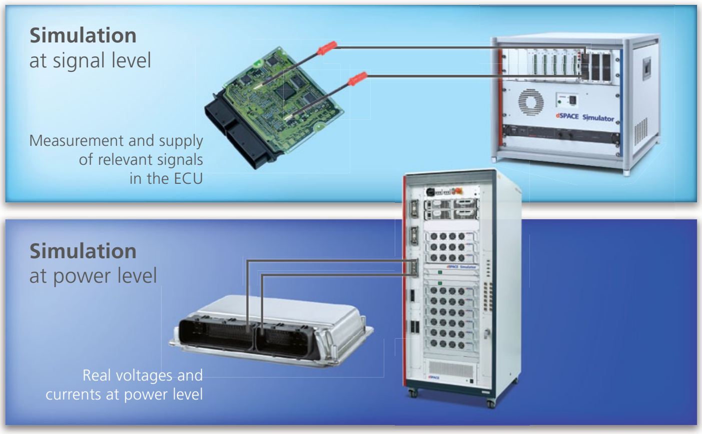
Cost-Efficient 48 V Mild Hybrid Technology

Today's conventional hybrid vehicles have an electric drive that is connected directly to the combustion engine. This requires profound modifications in the overall vehicle design and complex electrical components. Development time and costs increase enormously, causing high purchase prices for the end customer. Mild hybrid systems are a compromise that improves fuel efficiency and minimizes the conceptual changes to the vehicle body. These systems only support the combustion engine, driving on electrical power alone is not possible. For example, the electric motor is coupled with the combustion engine via a belt drive to replace the starter and alternator. This concept has enough flexibility for higher integration levels. For example, to attach the electric motor to the crankshaft or the transmission input shaft. A separate battery is required to supply power to the electric drive.

Integrated Motor Starter Generators

To take advantage of the opportunities of 48 V systems and to meet their requirements, automotive suppliers are developing electric motors that are designed as integrated motor starter generators (MSGs) and coupled to the internal combustion engine. This innovative drive component combines four functions into one system: brake energy recuperation, torque support during start-up, an especially comfortable start-stop control, and

>>



Testing control devices, including power stages: For simulation at power level, the actual currents and voltages of the control system are emulated at the ECU's power output stage (bottom). Simulation at signal level is performed on the opened ECU with signals picked up or input in front of the power stage (top).

energy-efficient coasting. The generator is designed for a capacity of approximately 10 kW. The electrical energy is stored in a compact lithium-ion battery that is no bigger than a conventional starter battery. Vehicles without a 48 V power supply or with conventional 12 V components have a (bidirectional) DC/DC converter to operate the 12 V batteries and components. All functions, and an inverter for generating AC voltage, are integrated into one controller. As an option, the DC/DC converter can be placed in a separate housing. This combines the control electronics and power stages for the motor currents and voltage conversion.

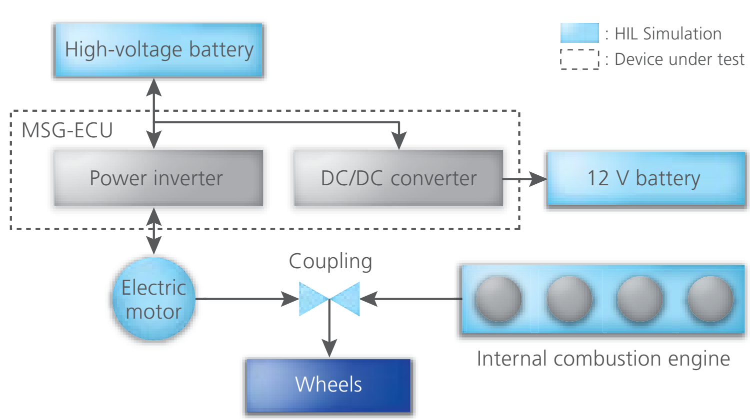
Requirements for ECU Testing

The Korea Automotive Technology Institute (KATECH) acts as a service provider and offers the Korean automotive industry a testing service to validate the functionality of the safety-relevant MSG controllers adequately and efficiently. The goal is to provide a test system that is simple and comfortable to use, and that can be connected directly to the control devices of different integration levels and from different manufacturers. This requires simulation at power level, because the devices under test must usually be modified for simulation (i.e., opened) in order to separate the control section from the power section and make it accessible for simulation. More often, this is a problematic task because the devices under test are often purchased parts or are inextricably linked to each other due to the high level of system integration. For this task, the simulator must emulate the electric motor at power level so the actual motor currents and voltages are accurately represented. This is a particular challenge. On the one hand, high currents in the range of 250 A continuous current and up to 550 A peak current must be processed. On the other hand, a high dynamic range is required to realistically simulate the electrical devices.

Simulator Concept

For KATECH, it was important to obtain the best possible integrated test system, where all the important components come from a single source. dSPACE was commissioned to design a simulator and put it in operation. Reflecting the dynamics of the control system, the concept provides two computing platforms. The first is a processor-based platform (DS1006 Processor Board with a quad-core) to simulate the vehicle electrical system, the vehicle mechanics and the restbus. The second platform (DS5203 FPGA Board) is based on a field-programmable gate array (FPGA) and is optimized for the highly dynamic processes of electric motor simulations. Specific power output stages, called electronic loads, generate the currents

The mild hybrid drive's control unit (MSG-ECU) as a device under test and the components to be simulated (high-voltage battery, 12 V battery, electric motor).



of the electric motor from the FPGA signals. All simulated components are calculated with plant models that are included in the dSPACE model libraries, the Automotive Simulation Models (ASM), and the XSG Electric Components Library.

Simulator Structure and Performance

The simulator's components are integrated in a 19-inch cabinet. The terminal voltage of the emulated high-voltage battery is provided by two parallel regulated power supplies. The power output stages for the motor emulation are made by six DS5381 Electronic Load Modules. They emulate the AC motor's three phase currents. For each phase, six modules are connected in parallel to continuously provide motor phase currents of 250 A_{rms} and peak currents of 550 A_{peak} for 10 seconds. Three additional load modules are used to build a 12 V_{DC} source/sink with ±170 A_{DC}. This provides the load for the DC/DC converter under test and emulates the connected 12 V network consisting of consumers and the battery.

The test system comprised of a dSPACE Simulator and the connected ECUs.

Special Features of the Simulator

The simulator is not only able to handle high currents. It also provides excellent energy efficiency, is designed for high simulation quality and can emulate different types of engines.

- *Energy efficiency through recuperation:*
  Through power circulation between the ECU under test and the electronic loads via the 48 V DC link, the simulated effective power might be significantly higher than the power consumption of the electronic load, regarding the power drawn from the mains. The power supply unit covers only the power dissipation of the ECU under test and the electronic loads. This results in a low connected load for the simulator, which is significantly lower than the performance of the ECUs under test. Feedback of energy to the mains is not necessary.
- *Simulation quality:*
  Representing the highly dynamic effects of electric machines in the simulation exactly enough requires cycle times of a few microseconds. This is done with FPGAs, which characteristically have fast parallel processing and low I/O latencies. The simulation models of the XSG Electric Components Library, designed especially for FPGAs, use this technology to achieve high

>>

> "The extremely fast FPGA computing platform from dSPACE and the XSG models for electrical components meet our requirements for precise electric motor simulation."

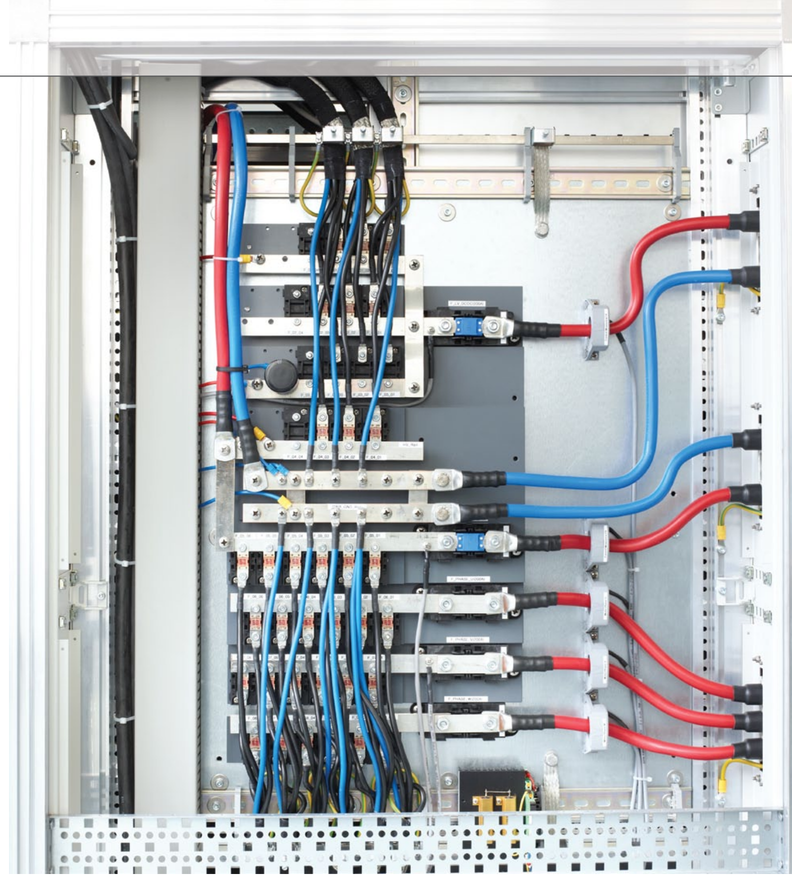
Raecheong Kang, KATECH

Korea Automotive Technology Institute

Established in 1990, the Korea Automotive Technology Institute (KATECH) is based on the Industrial Technology Innovation Promotion Act under the authority of the Korean Ministry of Trade, Industry & Energy (MOTIE). The institute supports the regional auto parts industry, in particular small and medium-sized businesses. To foster continued growth, it supports research and reliability tests and provides technical facilities and human resources.

Words of Thanks

This project was fully conducted under the Industrial Infrastructure Program for Fundamental Technologies (M0000022) funded by MOTIE, Korea.



The wiring inside the simulator. The built-in cable cross-sections indicate the high currents to be processed.

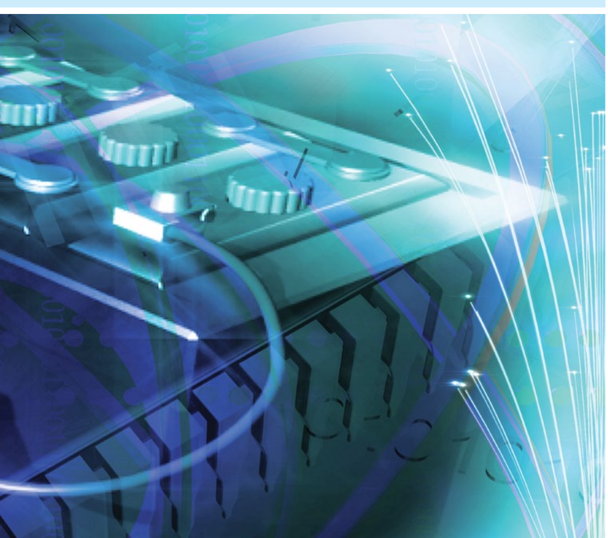
simulation performance. The XSG model library provides operation-ready components such as engine models, encoders, filters, etc. The simulation signals of the FPGA are implemented at power level via load modules. This is done with cascade-switching MOSFET power stages that reach switching frequencies of up to 3.2 MHz, thereby ensuring a highly dynamic simulation of the electric motor currents.

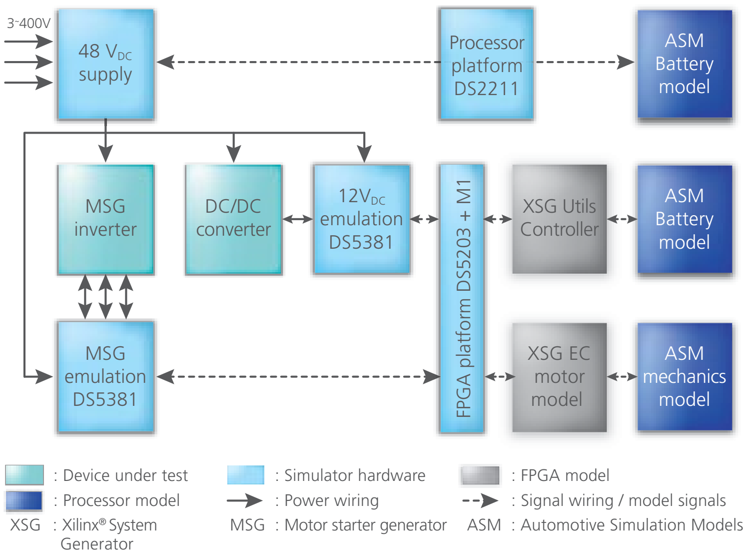
- *Flexibility:*
  The highly dynamic engine simulation via the dSPACE FPGA platform and direct current injection through the electronic loads make it possible to emulate various different motor inductances. No additional passive components are required, so the maximum simulatable phase current can be increased simply by connecting the load modules in parallel. Overall, this allows motors of different designs and different parameters to be tested on the same system.

Evaluation of the Test System

With the dSPACE Simulator and the included electronic load modules, dSPACE provides KATECH a test system for validating MSG control units from different vendors and integration depths easily and reliably. With the system, the testers achieve a high test depth, because the ECU is operated at power level without any modifications and because system-related couplings are taken into account (e.g., through reactions of the 12 V vehicle electrical system). The simulation quality and system reliability have been

> "The dSPACE Simulator, together with the electronic loads, is essential for validating the ECUs of mild hybrids."
>
> *Kiyun Jeong, KATECH*





Setup of the simulation environment with the device under test (DUT) and the simulated components.

proven in practical use. Simulation at power level has significant advantages over alternative approaches, such as mechanical test benches, because there are absolutely no setup times for mechanical modifications on the simulator. The system has no moving or rotating parts, so it can be operated in the laboratory without expensive structural safeguards. One of the reasons why the simulator is so attractive is that the properties of new devices under test can be adapted easily simply by pressing a button or changing the model. ■

Kiyun Jeong, Raecheong Kang,
Korea Automotive Technology Institute (KATECH)

Conclusion

The new 48 V power supply system is the basis for efficient, cost-effective hybrid drives with starter/generator technology. KATECH provides the Korean automotive industry and their suppliers with test equipment and know-how for validating engine ECUs at power level. To simulate the motors, KATECH uses highly dynamic loads, models, and a simulator from dSPACE. This system makes it possible to validate the ECU, inverter and DC/DC converter reliably. By using highly dynamic HIL components that can be operated in the range of 250/550 A, this test system is able to validate the functionality of modern ECUs of mild hybrids at power level.

Kiyun Jeong
Kiyun Jeong is the director of the Intelligent Control System Research Center at KATECH in Chungnam, Korea.

Raecheong Kang
Raecheong Kang is a senior researcher responsible for modeling and operating a HIL simulator at the Intelligent Control System Research Center at KATECH in Chungnam, Korea.