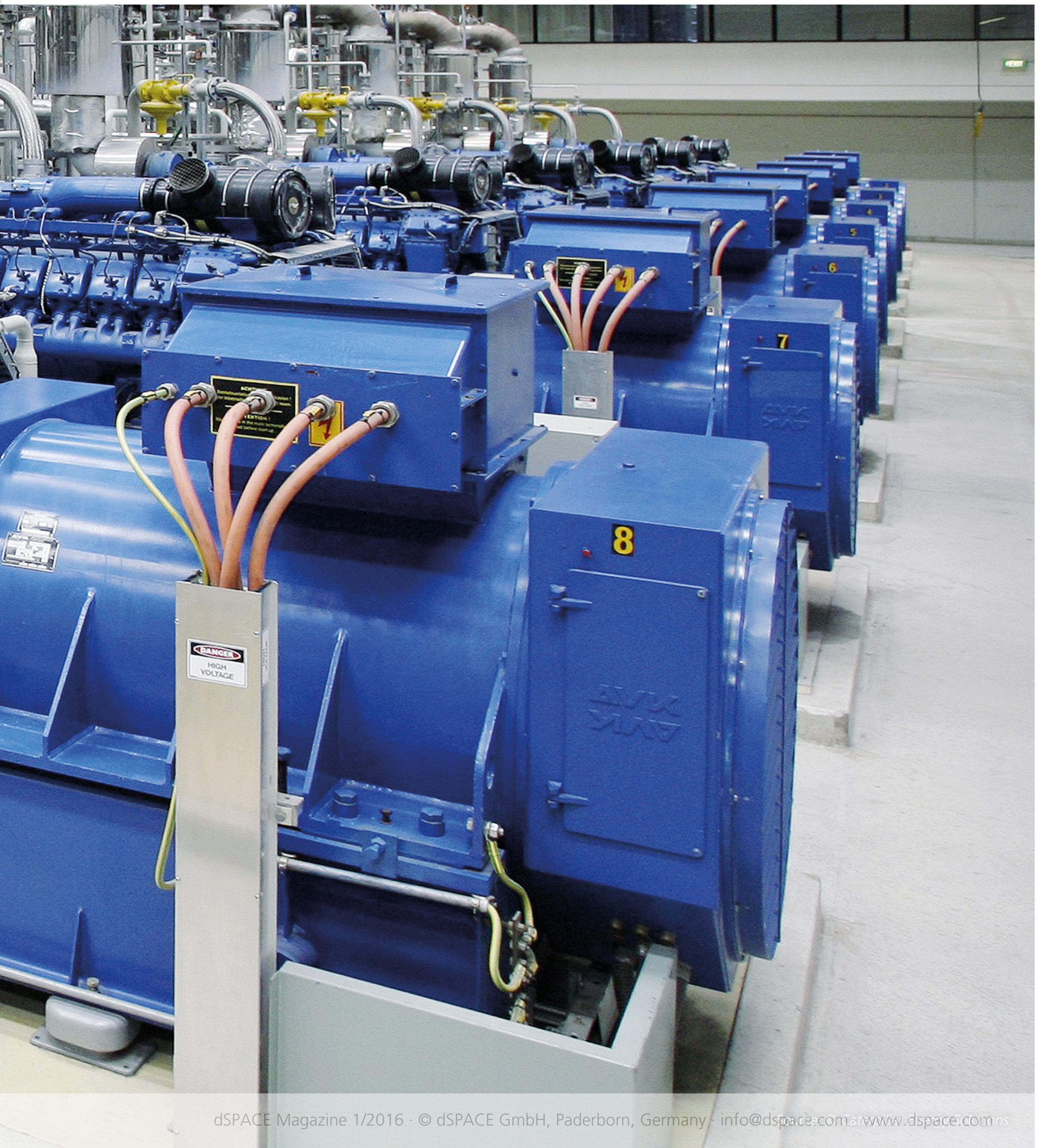
Top Performer

Controlling high-performance gas engines for energy supply

One thing is for certain: If you start a large high-performance gas engine with a suitable generator, you are the best-motorized employee on site – at an electric power of up to 4,500 kW. Such powerful machines are used primarily for the stationary generation of energy and heat. Caterpillar Energy Solutions developed an entirely new control to ensure that future energy plants remain efficient, dynamic, and maintenance-friendly.



Plants for decentralized energy generation can be used in many different fields. They can be used as independent power producers (IPP) to ensure a flexible and powerful energy supply in places that would otherwise not have power at all, such as remote areas where raw materials are being extracted, barely developed settlements, and areas where using the existing infrastructure would be too expensive for several reasons. In addition, the industrial and agricultural sectors often produce flammable gases as a by-product. It can therefore make sense to use these gases for one’s own energy supply, to feed the generated energy into the public grids for a financial benefit, or to resell the energy directly, e.g., to neighboring production plants. These independent power producers, consisting of gas engines and generators, are also very well suited for covering the peak loads of the public power grid. The machines are furthermore used to produce process heat, e.g., by generating hot water or water vapor, and to reuse waste gas directly, e.g., for CO_2 fertilization in greenhouses.

Complete Plants for Generating Energy and Heat

Caterpillar Energy Solutions GmbH is one of the leading providers of highly efficient, environmentally friendly holistic systems for decentralized energy and heat generation. The product range of the brands Cat and MWM includes gas engines, customer-specific power plant solutions, complete turn-key systems, container cogeneration plants, and flexible modular gas power plants that are easy to set up, economical and environmentally friendly. The company also offers comprehensive advice, plant design, engineering services for installing systems and putting them into operation, and worldwide services such as customer support and maintenance.

Gas engines for energy generation.


Source: © Caterpillar Energy Solutions

Requirements for Operating Gas Engines

A reliable power plant is particularly important for applications without access to the public power grid, which have to produce energy independently. In parallel grid operation, the consumers can still use the public, integrated power grid if necessary. In isolated grids, however, consumers depend on the few energy providers in a small area, and power supply sometimes hinges on only a few gas engines. But to cover peak loads, the public grid needs a power supply that is reliable and readily available. This also applies to heat generation. Reliability, efficiency, and flexibility are therefore the holy grail of energy supply. These three factors are, in turn, closely connected to maintenance, because a machine should require as little servicing as possible, while operation downtimes have to be kept short and maintenance costs low. In addition to further developing the engine mechanics to minimize the use of lubricants, the control development team is working on methods to minimize the costs of maintenance. Therefore, the mechanical factors are just one part of the solution. Rather, a sophisticated electronic plant control is needed to meet the requirements.

Towards a New Plant Control

The goal of Caterpillar Energy Solutions is to use this new control to make future plants even more efficient, flexible, and maintenance-friendly, and to use the newly developed control across the entire product range. Therefore, the company decided to replace third-party electronic control units (ECUs) in future plants with their own electronic control units. When applied to gas engines for energy production, this task can be even more challenging than for conventional combustion engines (e.g., for passenger cars). The costs, size, and production time for one high-performance gas engine are considerable, and there are many product variants, so it is usually not possible to have special prototypes for testing. The development team therefore constantly faced the risk of severely damaging the real engine when performing tests at the limits and under high loads due to intensive testing of start, stop and emergency stop behavior, which would cause extremely high costs and delay the project. Testing also had to be possible before a real engine was available. It was therefore all the more important to test the engine control system in offline function development (software-in-the-loop, SIL) and on a hardware-in-the-loop (HIL) simulator, in the plant network and with a HIL system of the superordinate control system. Another requirement of Caterpillar Energy Solutions was to make the HIL simulation environment flexible and scalable to test the many engine variants, and to make it a fundamental element of future software release processes with the aim of becoming more and more independent of physical testing with real engines. >>

Motor Specification

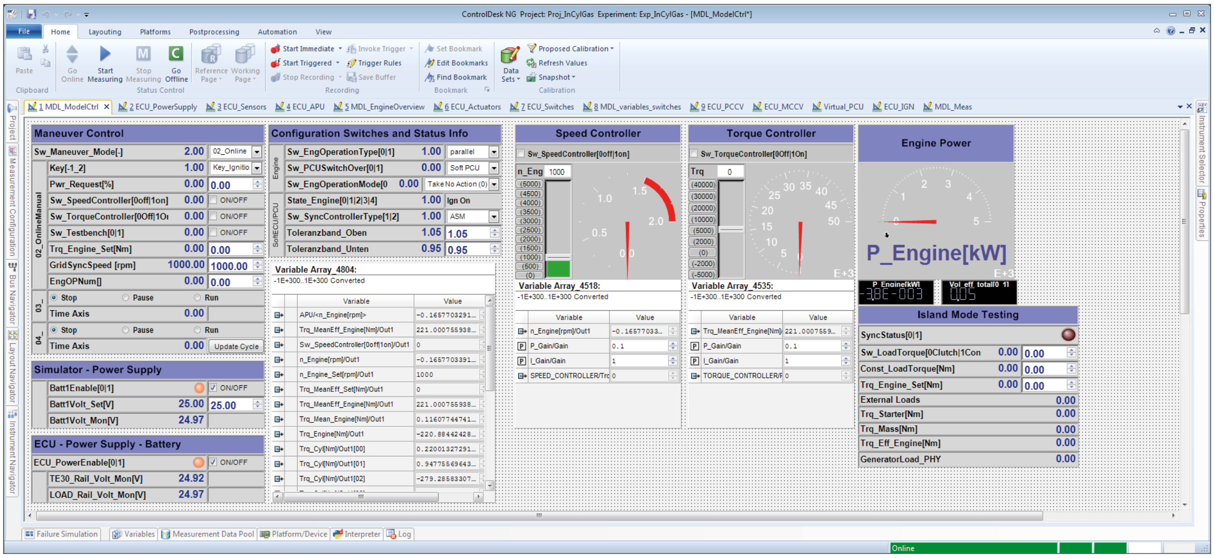
- Cylinders: 8 - 20
- Power range: Usually 400 - 4,500 kW_{el}
- All gas types: Natural gas, landfill gas, sewage gas, mine gas, coke oven gas, biogas
- "Traditional" engine control (e.g., throttle valves) plus process control (e.g., for cooling, gas pressure, electrical phases)
- Special emergency strategies (e.g., emergency stop)

The high number of cylinders to be controlled required a particularly efficient simulation model for SIL and HIL testing.

Ralph Staudt (left) and Sreenivasa Ravipati (right) of Caterpillar Energy Solutions used a dSPACE Simulator to perform extensive HIL testing of the engine ECU.

> "As a supplier for tools and engineering services, dSPACE has been our go-to partner for the many detailed questions about our HIL system, from simulator specification to closed-loop operation with the real ECU. This helped us speed up the project considerably."

Magnus Euler, Caterpillar Energy Solutions



Experiment control with ControlDesk Next Generation.

Requirements for the Simulation Model

To simulate a gas engine for ECU development, the simulation model has to replicate the specific engine characteristics precisely enough. The scope and quality of the simulation have to be high enough for the specific use case and supply the ECU with plausible values for all work steps. Caterpillar Energy Solutions particularly considered industry-proven models that are easy to adjust to the characteristics of gas engines. This resulted in the following requirements for the plant model of the combustion engine:

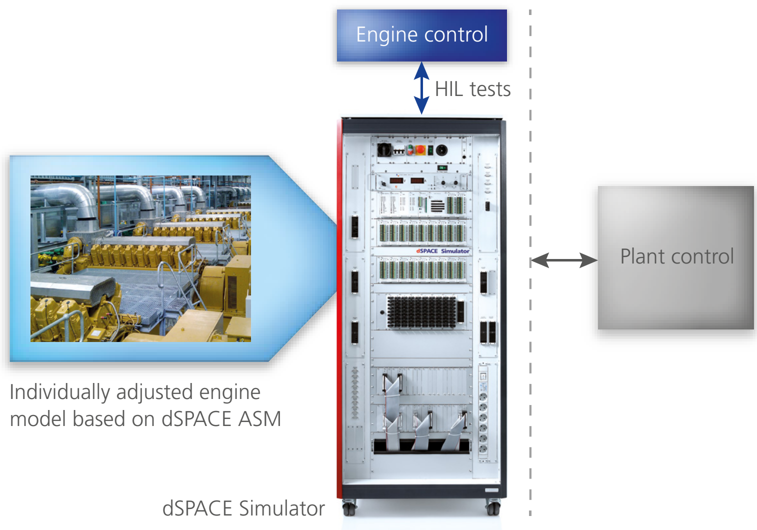
- An adjustable open model architecture that can also be used with gas engines for energy production
- High computational efficiency for real-time simulations with up to 24 cylinders
- A high quality of detail to suitably address potential cylinder pressure sensors
- Flexible parameterization of the model with simulation data with a limited number of load points

dSPACE ASM for Gas Engines

With the support of dSPACE Engineering Services, it was possible to adjust the original ASM Gasoline Engine InCylinder model – an open, granular Simulink® model – for Caterpillar Energy Solutions so that it can now be used to simulate gas engines. The model was adjusted in several steps:

- Partially reusing library blocks to adjust the basic model to the specific engine schema with units such as intercoolers and valves. This entailed only a reasonable amount of effort because by default the ASM model is parameterized for an engine topology with a twin turbocharger and V-engine architecture.
- Restructuring the automotive combustion engine model according to the requirements of the energy supply technology
- Changing the physical, chemical, and thermal parameters of the basic model
- Automatically optimizing the parameters by evaluating measurement values to improve the simulation results
- Validating the model via ASM Engine Testbench during offline simulation

> "With the ASM Gasoline Engine InCylinder model adjusted to our requirements, we were able to perform a sufficiently realistic yet real-time-capable simulation of the gas engine."
>
> *Magnus Euler, Caterpillar Energy Solutions*



By using a dSPACE Simulator and a modified model based on ASM Gasoline Engine InCylinder, Caterpillar Energy Solutions was able to perform early HIL tests of the engine control without the need for a real engine.

Testing the New Engine Controller

The plant and engine controller developed by Caterpillar Energy Solutions had to undergo testing in various areas. For example, the behavior of the controller and the engine before, during and after synchronization with the electrical phase has to be tested, including start, stop and emergency stop behavior, to guarantee smooth operation in a power grid. Offline function tests via SIL simulation and ECU tests on the HIL simulator were used. The specially adjusted ASM models were used in all test phases.

HIL Test System

A dSPACE Simulator Full-Size was used for HIL testing. The simulator is equipped with two expansion boxes that each contain a DS1006-based system with extensive I/O. This made it possible to perform powerful multicore and multiprocessor operations, especially for reducing simulation times by computing the ASM model separately from the I/O. The dSPACE simulator also contained modules for signal conditioning, a Failure Insertion Unit for inserting electric faults, and modules for current measurement and load simulation. Real loads, such as injectors, throttle valves, and wastegate valves, were used for testing. The simulator was also connected to the larger HIL system of the plant control. All the simulation tasks were executed with dSPACE's experiment software ControlDesk® Next Generation. ■

Magnus Euler,
Caterpillar Energy Solutions GmbH

Conclusion

The new plant and engine control system developed by Caterpillar Energy Solutions laid the foundation for even more efficient, flexible, and maintenance-friendly Cat and MWM products. The fact that dSPACE provided a one-stop solution for important tools as well as engineering and support services significantly contributed to the success and quick implementation of the project. By frontloading many tests to SIL and HIL simulation, Caterpillar Energy Solutions was able to perform a large share of the development work before the real engines were available. These tests then did not have to be performed on the expensive real engine later on. This, in turn, shortened the time needed for development. The dSPACE tools were used to create a development environment for engine ECUs across the entire product range and for engines with different numbers of cylinders. ASM is already being used in new engine development projects.

Magnus Euler
Magnus Euler is head of Engine Control in the Electrical Engineering department of Caterpillar Energy Solutions GmbH, Mannheim, Germany.