Testing Fuel Cell Technology

- Alternative propulsion concept developed with dSPACE technology
- Closed simulation environment
- Seamless, model-based development chain

General Motors (GM) and Opel are working on bringing hydrogen vehicles with fuel cell propulsion up to production level. To ensure the success of the development process, they have set up a closed simulation environment and are using simulation models in various process phases. Several dSPACE products – MicroAutoBox, dSPACE Simulator, ControlDesk, AutomationDesk, etc. – have been fitted seamlessly into the overall development chain, where they are making a major contribution.

The Road to HydroGen3

As vehicle numbers increase throughout the world, with a concomitant rise in fossil energy consumption and the effect this has on the environment, the automotive industry faces the challenge of developing alternative systems of propulsion. Hydrogen-powered vehicles have the most potential in the search for a viable alternative to combustion engines. Against this background, GM and Opel set up the GM Fuel Cell Activities (GM FCA) development center in November 1997. The aim: to bring fuel cell technology up to production level. GM and Opel have so far invested over a billion dollars in the venture. Today, around 600 employees are working on different aspects of the joint fuel cell program at five different locations – in the USA (Rochester, Warren, Torrance), in Germany (Mainz-Kastel), and in Japan (Tokyo). The latest result of their work is the "HydroGen3", an experimental vehicle based on an Opel Zafira.

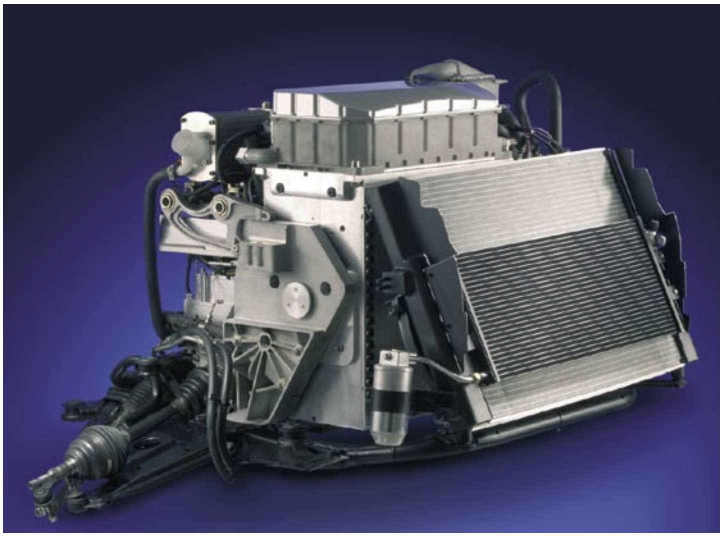
▲ *One of the HydroGen3 experimental vehicles.*

Compact Power Plant Under the Hood

The heart of the HydroGen3 is its fuel cell stack, a compact, highly efficient power plant that fits under the Opel Zafira's front hood together with the electric motor and ancillary units. GM FCA developed the fuel cell stack with 200 single cells connected in series, in which hydrogen and oxygen react in an electrochemical process to generate electrical energy. This is used to drive the HydroGen3's electric motor, which has an output of 60 kW/82 HP. The unit, with a maximum torque of 215 Nm, takes the fuel cell Zafira from zero to 100 km/h in around 16 seconds and reaches a top speed of 160 km/h. As regards the tank system, GM FCA is using a dual approach. Some of the experimental vehicles, called "HydroGen3 liquid", have superinsulated tanks that hold extremely cold, liquid hydrogen. Others, called "HydroGen3 compressed 700", have high-pressure tanks that store gaseous hydrogen at pressures of up to 700 bar.

Extensive Simulation

The control system for the fuel cell propulsion unit is being developed in a seamless process closely based on the classical V-cycle. The ability to slot simulation



▲ *The fuel cell stack – the power station under the hood.*

technology into all phases of the development process is particularly important. Over the years, GM FCA has accumulated a wealth of sound specialist know-how on fuel cell propulsion. Specific modeling tools such as MATLAB®/Simulink® were used to create a closed simulation model of the overall system. This consists of components for the fuel cell propulsion system (FCPS), the FCPS controller, the vehicle plant model, and the restbus simulation of other electronic control units (ECUs). The fuel cell propulsion system itself is split into subsystems (electric storage system, fuel cell power module, electric traction system, cooling system, H2 storage system, and driver interface). The model of the vehicle platform closely follows the design of the actual production vehicle.

Using dSPACE products means that the simulation models that are developed can be used in several different process phases – that is, not only during model-in-the-loop simulation but also in rapid control prototyping (RCP), hardware-in-the-loop (HIL) simulation, and others. Moreover, the model of the overall system is the basis for further applications. It is not only used to develop the FCPS controller, but also to operate the test benches, perform system integration, and develop operating strategies.

Developing the FCPS Controller

Following extensive offline simulations at the workstation, the developed FCPS controller was initially tested without production-close ECUs, simply by using dSPACE's MicroAutoBox as a prototyping system. Autocoding was used for easy transfer of the controller model to the MicroAutoBox. Then after successful fullpass prototyping, from 2004 onwards the E67 production ECU (from GM Powertrain) was used for the FCPS controller. Functions that are still under development are implemented in bypass mode via the MicroAutoBox. Today, FCPS controllers for preproduction development are being tested both in HIL test benches (based on dSPACE Simulator Mid-Size) and in a fleet of test vehicles.

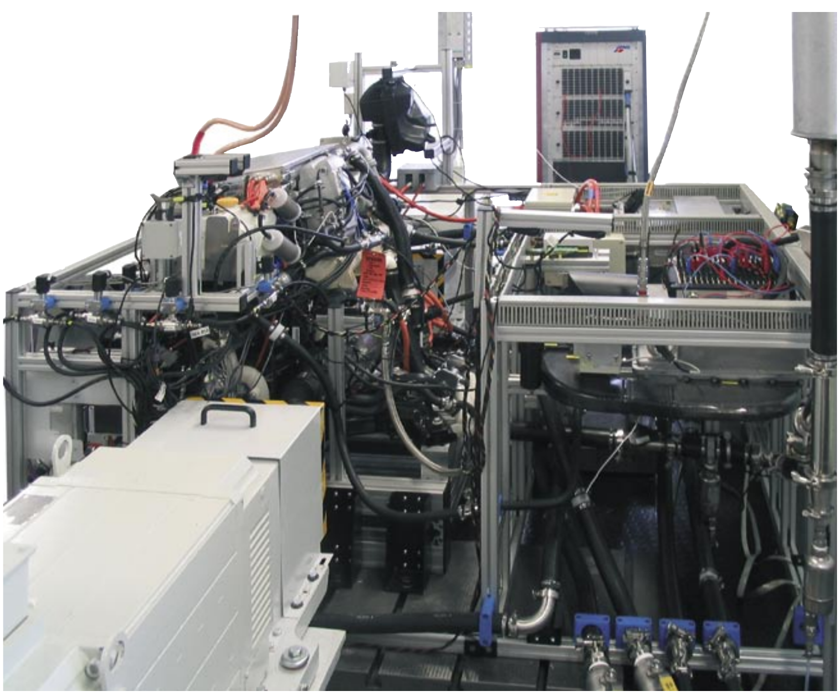
Using HIL Simulation on the Test Benches

Responsibility for developing the individual parts of the fuel cell propulsion system is distributed across

several GM locations. Yet despite parallel development at different locations, HIL simulation enables GM FCA to perform early validation of both the FCPS controller and the subsystems any time they need to do so. A dSPACE Simulator Mid-Size is currently being employed to operate fuel cell propulsion test benches with dynamometers and pure fuel cell test benches. In each case, the HIL simulator works together with the object under test, standing in for specific subsystems or ECUs that are not present in reality. The relevant simulation models from MIL simulation can be reused for this with very little adjustment. The dSPACE software used includes ControlDesk for setting up simulator user interfaces and AutomationDesk for automatic operation of the fuel cell test bench.

Advantages of HIL Simulation

The simulated components can be successively replaced on the HIL test bench by their real counterparts. It is no problem to switch back and forth between model and real object, so complete tests can be run on the closed system at any time.
Early tests on the HIL test bench investigate the connections to adjacent subsystems and ECUs. This provides greater maturity and higher quality at subsystem level very early on, thereby considerably reducing the effort involved in later system integration.



▲ *Fuel cell propulsion test bench with dSPACE Simulator.*

Summary and Outlook

To develop the hydrogen propulsion system, GM FCA implemented a seamless, simulation-aided development environment. MIL and HIL simulations proved valuable components in the control development environment and the fuel cell test benches. The overall simulation environment can be flexibly configured for different operational modes (offline/HIL/restbus simulation), with very little software modification. Model-based development allows offline workstation simulation, real-time simulation at HIL and system test benches, and control prototyping on test benches and in vehicles. Using the dSPACE products makes simulation technology an integrated component in all phases of the development process. This means that the same versions of the control software can be used for test benches and vehicles, and there is no special test bench software that would require extra maintenance.

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