Fuel Cell Revolution

Toolchain for Developing a Fuel Cell Control System

For the past 20 years, Ford has gained a wealth of experience from their research and development of fuel cells for in-vehicle use. Ford's researchers have tested several concepts in the laboratory and on the road. Thanks to this continuous development work, the new technology is approaching commercial viability.

Fuel Cell Systems and Their Control

Fuel cells transform chemical energy into electrical energy. When reactants such as hydrogen and oxygen are supplied to a stack of fuel cells, the resulting electrons can be harnessed to propel automobiles. The electronic control regulates an efficient delivery of the reactants to the fuel cell by monitoring and controlling the flow, concentration and pressure.

Control System Challenges

Early prototype designs like the P2000 used standard ECUs with purpose-built, customized I/O for fuel cell applications. But this architecture left little room for experimentation. When Ford began internal development of control algorithms for fuel cells, typical constraints such as timing, personnel, logistics, and budgets made it necessary to switch from a standard electronic control unit (ECU) to a flexible rapid prototyping system. A well-integrated control system was desired that could drive multiple valves, which control and route the hydrogen, air, and water within the fuel cell system. At the same time, high flexibility and modularity was absolutely essential because I/O demands can quickly change at any time during the research and development of electronic systems. Another challenge was the planned simultaneous introduction of a purely model-based work method.

Ultimate Flexibility with Rapid Control Prototyping

Ford decided on a rapid control prototyping (RCP) system consisting of a dSPACE MicroAutoBox II and dSPACE RapidPro Power Unit, as well as Simulink® from MathWorks (figure 1). The determining factor behind this decision was the positive experience with dSPACE RCP systems in several research and development divisions at Ford. The system provides the desired flexibility because it can be adapted to

The Ford REFL3X concept car, introducing an electric propulsion system.

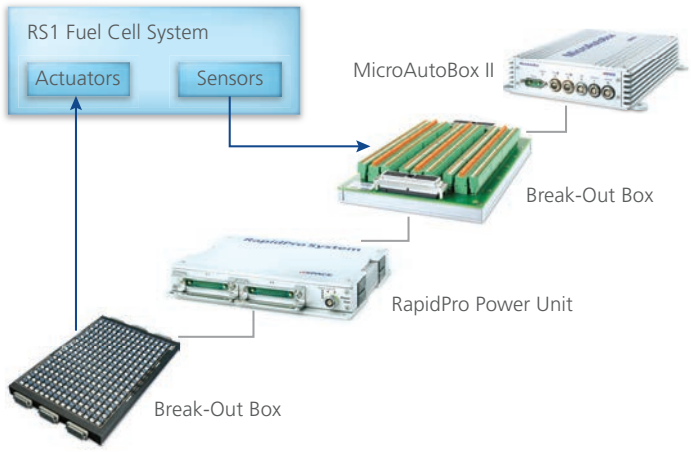


Figure 1: Interface from the RapidPro Power Unit to MicroAutoBox II.

> "dSPACE engineers were by our side from project inception through the detailed implementation, supporting wherever and whenever needed."
>
> *Kurt Osborne, Ford*

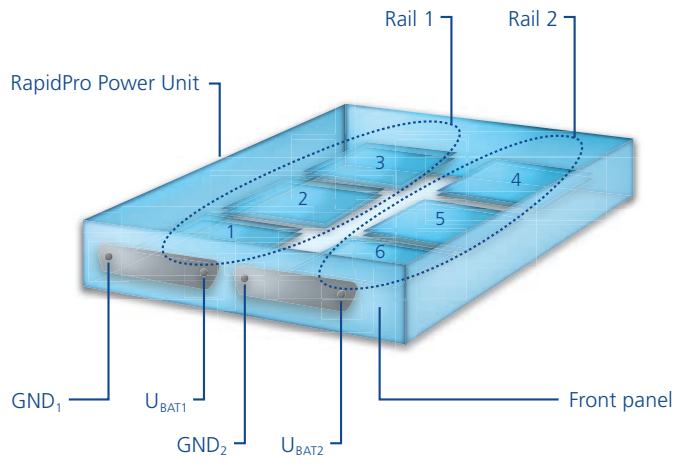
meet the fuel cell control system requirements by adding any necessary supplementary I/O and interface modules, power units and signal conditioning units.

In-Project Benefits of Using RapidPro

The signals from the sensors and actuators of the fuel cell could be processed directly with the same RapidPro standard modules that are used in regular combustion engine applications. For the majority of the actuators, low-side driver (LSD) modules were used. The electronic throttle body in the air delivery subsystem was controlled by a full-bridge driver (FBD) module. Since the fuel cells are driven by two different supply voltages, the split voltage bus provided by RapidPro was especially beneficial: two separate power rails feed the two respective supply units (figure 2). These are just some of the advantages of rapid prototyping systems.

They are examples of the experience and ingenuity of dSPACE engineers who were on hand from project inception through the detailed implementation, supporting wherever and whenever needed.

Figure 2: Two rails in RapidPro allow for twin independent power supplies.



Convenient Configuration

Operating and configuring the RapidPro Power Unit for the application at hand is done with dSPACE's software ConfigurationDesk and its graphical, intuitive user interface. For example, ConfigurationDesk allows a user to assign channel names corresponding to actuators and sensors and to configure settings for each of the channels. At any time, the user can export a channel list indicating the location of modules in their corresponding slots and the channel names with their assigned pins. ConfigurationDesk makes handling the configuration and documentation tasks very easy.

Diagnostics

With its diagnostic functions, the RapidPro Power Unit uses a serial peripheral interface (SPI) to prepare data that can be monitored immediately in ConfigurationDesk. What is more valuable, though, is that this data can be time-aligned to other system events and thus logged better. For this task, the RTI blocksets

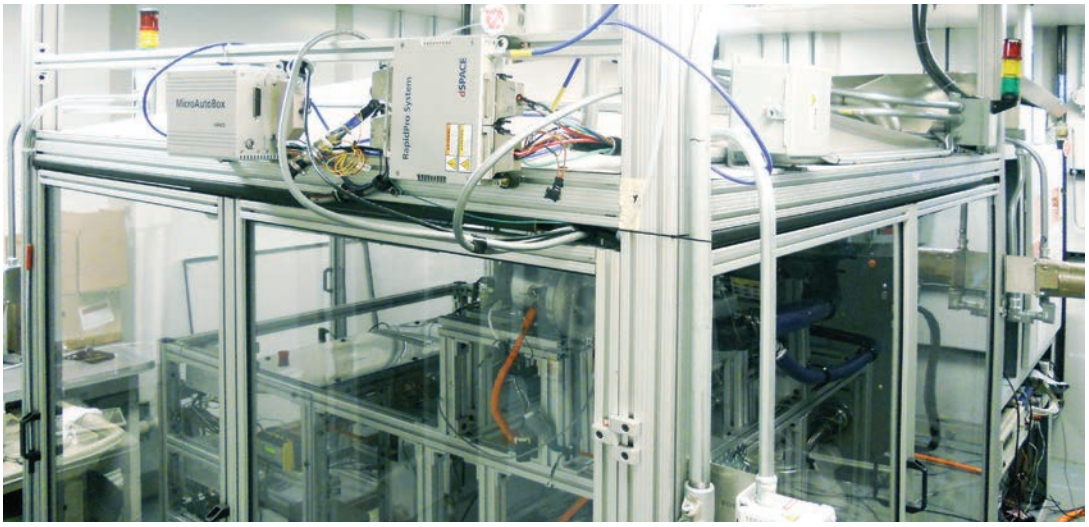


Figure 3: Lab setup of the fuel cell system with MicroAutoBox and RapidPro.

for Simulink are available to poll the I/O channels. The recorded data is processed further in ControlDesk. To use the diagnostic information in other test system controllers, it is retransmitted via CAN messages.

Evaluation and Next Steps

The rapid prototyping systems MicroAutoBox and RapidPro proved themselves to be extremely useful for controlling fuel cell systems during research and development at Ford. All of the specified functions were able to be implemented in the fuel cell system, which is attributable, in part, to the coordinated tool chain. The RapidPro Power Unit fulfilled all of the needs for a flexible and reconfigurable power stage. The RapidPro systems allowed a small team with a limited budget to implement and test new fuel cell concepts without focusing on the optimization details that would have been required for ECUs. The switch to one common tool chain was surprisingly easy.

In near future, the system will undergo validation testing in freezing ambient conditions. If additional components or novel strategies become necessary, the configurability of the RapidPro Power Unit will allow rapid integration of those components into the control system.

One of the next steps could be integrating the fuel cell system into a demonstration vehicle. In this case, Ford will be able to use the RapidPro Power Unit from the very start. Thanks to its short boot times, the RapidPro Power Unit is very fast, making it compatible with vehicle applications. Furthermore, the RapidPro Power Unit can be selectively disabled by the MicroAutoBox thus saving energy and improving overall energy consumption. ■

Kurt Osborne
Dr. Miloš Milačić
Ford Motor Company

Kurt Osborne
Kurt Osborne is the fuel cell controls technical expert and is the leader of global model-based fuel cell system control design at Ford Motor Company in Dearborn (MI), USA.

Dr. Miloš Milačić
Dr. Miloš Milačić is responsible for fuel cell control algorithm development and implementation at Ford Motor Company in Dearborn (MI), USA.