

University of Waterloo's Hydrogen Fuel Cell Choice Meets the Reality of Canada's Winter by Using Model-Based Design

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ABSTRACT

Developing a hydrogen fuel cell vehicle in three years is not a trivial task for any group of engineers. It is even worse still when you consider the climate it will be subjected to in Canada. For four months of the year, our vehicle remains inside of a heated garage, away from the cold ice and snow. Actual vehicle data is collected during the eight warm months of the year to construct empirical models. Software-in-the-loop and hardware-in-the-loop methodologies were used to tune our vehicles using the models that were constructed using actual vehicle data. Without MATLAB and Simulink from The MathWorks, our winters would be a lot less productive.

In this paper, you will find a brief overview of our vehicle's architecture as well as how model-based design was valuable to our design and implementation of our vehicle.

Keywords: Model-based design, MATLAB, Simulink, Software-in-the-loop, Hardware-in-the-loop, Component-in-the-loop.

INTRODUCTION

The need for environmentally friendly vehicles is becoming more apparent with the increased awareness of our dependence on the depleting source of fossil fuels. Student competitions have traditionally paved the way for emerging undergraduate and graduate students to use their skills to develop cutting edge technology for the automotive sector.

The Challenge X student competition is a competition that allows schools from around North America to develop a hybrid powertrain to be used in a 2005 Chevrolet Equinox using one of four alternative fuels; biodiesel, ethanol, hydrogen, and reformulated gasoline. Of the 17 schools in this competition, the University of Waterloo Alternative Fuels Team (UWAF) is the only team to use a hydrogen powered Polymer Electrolyte Membrane (PEM) fuel cell technology as the main source of propulsion. While using fuel cells has its

advantages, we are also at a disadvantage when it comes to development during the winter months.

The fuel cells that are used in UWAF's current vehicle uses only de-ionized water as its coolant. Also, during the operation of the PEM fuel cells, additional de-ionized water is produced at the cathode side, adding to the overall water content of the system. During climates where temperatures decrease below 4°C, the fuel cells are in danger of being damaged caused by the expansion of water when it begins to freeze.

The tools offered by The MathWorks enable us to continue work on the vehicle during the months where the vehicle remains indoors in a heated garage. Such tools include MATLAB and Simulink. Third-party software such as Argonne National Labs Powertrain Systems Analysis Toolkit (PSAT) and MotoTron's MotoHawk are built on the Simulink platform.

Using these tools, software-in-the-loop, hardware-in-the-loop, and component-in-the-loop simulation and analysis methodologies become possible during months where actual vehicle testing is not possible.

VEHICLE ARCHITECTURE

Much like a conventional hybrid that can be found on the roads of today, our vehicle uses much of the same concepts. The difference between our vehicle and conventional hybrids is in our primary power delivering unit; PEM fuel cells vs. combustion engines.

The components of the vehicles can be seen below in table 1.

Table 1: UWAF's vehicle components list

Component	Make/Model	Specifications
Fuel Cell Power Module	Hydrogenics/HYPM 65kW	Max Power 65 kW Voltage 190V – 300V Current 0 A – 300 A
Hydrogen Storage	Dynetek/ZM180	Max Pressure 5000 psi Tank Capacity 4.31 kg H ₂ Tank Volume 178 L
DC/DC Converter	Custom UWAF Design and Construction	Input Voltage 190V – 310V Output Voltage 300V – 380V Converter Type Boost
Motors (2 Units)	Ballard/312V67	Peak Power 67 kW

		Continuous Power	32 kW
		Max Torque	190 Nm
Motor Controller (2 Units)	Ballard/312V67	Continuous Power	67 kW
		Input Voltage	260V – 385V
		Output Current	280 A RMS
Battery Pack	Cobasys/NiMHax288-60	OC Voltage	275V – 336V
		Capacity	8.5 Ah
		Energy	2.8 kWh

Two challenges presented themselves when the team first chose these components; integration of the components and the control of these components. The integration was a very complex process since the components must fit into an existing framework.

Figure 1 below shows the layout of the powertrain components throughout the vehicle.

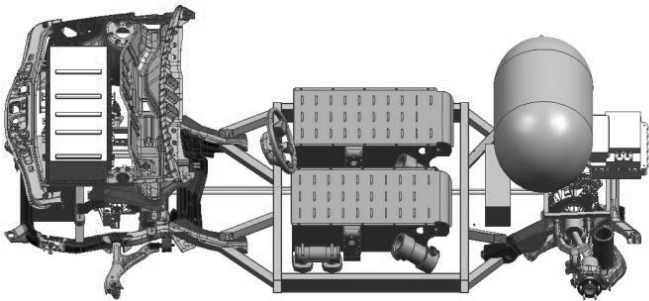


Figure 1: Powertrain layout of UWAF's fuel cell Equinox

The 70kW nickel metal hydride (NiMH) battery pack, 67kW three-phase AC induction traction motor, a high voltage DC/DC converter, 12V DC/DC converter, the high voltage distribution unit, and other electronics are packaged underneath the hood. The 65kW fuel cell power module is packaged inside of the vehicle in the floor area. This was the only location with enough space to house the power modules while also allowing for five-passenger seating. The main structural frame rails were redesigned since the fuel cell power module support frame will also provide the support for the vehicle's structure. The rear of the vehicle required extensive modifications to house a second 65kW traction motor as well as the supports for a hydrogen storage tank.

Our control system is the other hurdle; how is everything going to communicate with each other? How is everything connected to each other? These were questions that we asked ourselves during the initial construction of our vehicle. Figure 2 shows a simplified overview of our control system.

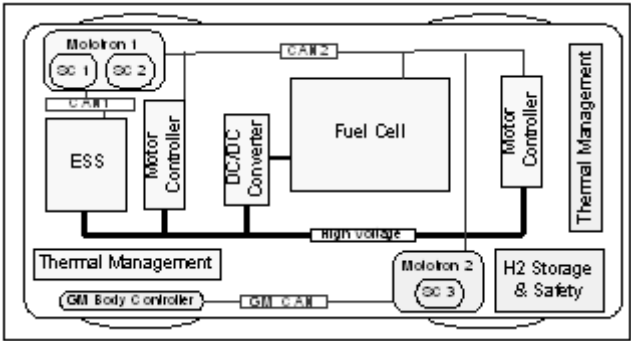


Figure 2: UWAF's Fuel Cell Equinox Control System

In order to develop an effective control strategy, it is impractical to use the actual vehicle and its components as the test platform. There is an unnecessary risk involved when going straight to the vehicle with an unproven strategy; this is where model-based design comes into the picture.

VEHICLE MODELLING

During the first year of the Challenge X competition, UWAF depending heavily on the use of Simulink and Argonne National Labs Powertrain Systems Analysis Toolkit (PSAT) to select the optimal Challenge X vehicle powertrain architecture. Once the optimal powertrain was selected, it was time to build more in-depth models that have the accuracy to allow us to perform control validation as well as accurate vehicle tuning. This also enables us to produce vehicle technical specifications (VTS) that is required by the competition.

Figure 3 shows the heuristics of the design method.

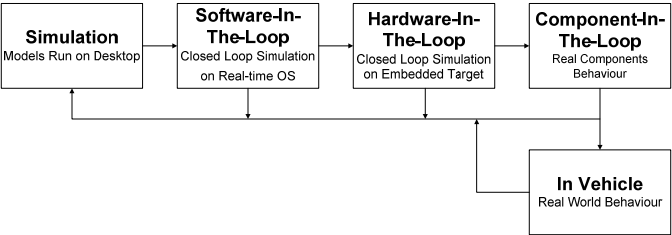


Figure 3: Design Heuristics

We will be focusing on the simulation, software-in-the-loop, and hardware-in-the-loop steps.

SIMULATION – During the simulation phase, component models are constructed and tested on the desktop environment. The models in this simulation can be run without taking into account the cycle times that certain components communicate in. This way, the simulations can be run quickly for faster construction of models. The software packages used here include MATLAB and Simulink, and PSAT.

SOFTWARE-IN-THE-LOOP (SIL) – The software-in-the-loop method allows for models and control strategies to