PSpice Simulation via AC Impedance for PEFC at Operational Loads

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The PEFC stacks in the HCore-500 and Nexa™ power systems were operated with room air and pure hydrogen (99.99%). Some of the fuel cells or the whole PEFC stack were separated from the embedded control system for AC impedance measurements. A 24 V rechargeable battery or another PEFC system was applied to power the electronic devices in the control system. Single MEAs, multiple MEA cell groups, and full fuel cell stacks were examined at various operational currents using an EG&G Model 273A/5210 system and a Gamry FC350™/TDI electronic load. The in-situ impedance data for separated cells and stacks were fitted to equivalent circuits by the non-linear least squares method (NLLS). AC impedance data were successfully measured at a high current of 35 A (*ca.* 291.7 mA/cm^2) for the Nexa™ PEFC stack using the Gamry/TDI system. PSpice simulated curves were obtained from equivalent circuit elements demonstrating good agreement with the experimental pulse data measured from the PEFC power system. AC impedance and PSpice simulation prove to be simple and trouble-free methods to implement real time diagnostic capability suitable for evaluating the peak pulse performance and the state-of-health of the fuel cells in the PEFC stack.

Keywords: PSpice simulation, AC impedance; polymer electrolyte fuel cells; fuel cell stack.

Polymer electrolyte fuel cells (PEFC) and systems attract wide interest in development and commercialization of vehicular, portable, and stationary applications. A wide range of the fuel cell products currently exists but the design, performance, and operation lifetime may have big difference due to various particular applications. The pulse capability is one of the fuel cell applications that requires extensive research and development work. Authors [1-2] reported PEFC work using electrochemical impedance spectroscopy (EIS), which describes the response of a circuit to an alternating current or voltage as a function of frequency. This EIS technique can use a purely electronic model (equivalent circuit diagram) to represent an electrochemical fuel cell. The equivalent circuit model closely describes the real physical phenomena in the PEM fuel cell system using nonlinear least squares fitting and data interpretation. In this work, the HCore-500-2 stack was analyzed by a traditional EG&G Model 273A/5210 system and the Nexa™ system was studied using a Gamry FC350™ [3]/ TDI electronic load because the Nexa™ PEFC stack usually has a high current output (up to 44 A amps). The simulated equivalent circuit elements from analyzing AC impedance data were applied to the real electronic circuit for PSpice pulse simulation.

The HCore 500-2 (H Power Corporation) and Nexa™ Power Module (Ballard Power Systems) were set up in the lab for EIS measurement. The HCore system has a nominal 48 VDC (39-65 VDC range) and 500 W power output capability. An EIS system including an EG&G Model 5210 two-Phase lock-in amplifier and a 273A potentiostat-galvanostat was used to evaluate on the HCore 500-2 fuel cells. For analyzing the fuel cells in the HCore 500-2 system, the control system and electronic devices were separated from the FC stack. This was achieved by providing a similar outside power source (24 V rechargeable battery and HP 6011A, E3611A DC power supplies) for the control operation.

The Ballard Nexa™ fuel cell system is a small fuel cell system providing 1200 watts of unregulated DC power at a nominal output volt-

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age of 26 VDC, its output current can reach 44 A and its voltage can reach up to 42 V. A Gamry FC350™ fuel cell monitor with a TDI electric load is capable of measuring the impedance of operating fuel cells at high current levels (Gamry Instruments, Warminster, PA). The fuel cell monitor uses the electric load to sink the fuel cell current. The experimental arrangement of the FC350, the TDI electronic load, and the fuel cell system are available from the manufacture. The sinusoidal current signal from the FC350, working in galvanostatic impedance mode, modulates the current from single or multiple fuel cell(s) or the PEFC stack. Simultaneously, the current information at the electric load is sent to the FC350™ monitor. The fuel cell voltage is measured by the FC350 directly. The FC350 collects these data and generates the impedance.

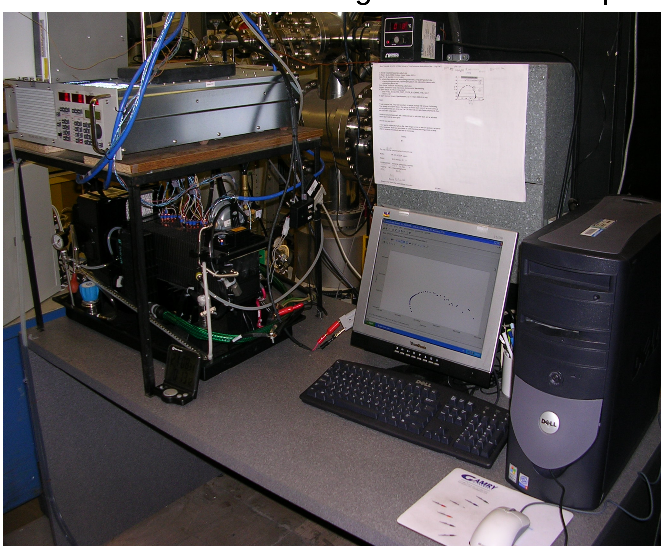

Figure 1. System configuration of Gamry FC350™ fuel cell monitor and Ballard Nexa™ PEFC stack for AC impedance measurement.

ance. The Gamry Hybrid EIS mode was applied for the experiments in order to observe the EIS behavior at low frequencies. Better results on ultra-low impedance analysis at a high power output can be obtained using the Gamry FC350 monitor and TDI electronic load.

A simplified equivalent circuit for the HCore-500-2 PEFC stack was applied to the NLLS fitting process. The three values of physical elements, *i.e.* R_{el}— uncompensated resistance related to the electrolyte, R_{ct}— charge transfer resistance, and C_{dl}— double layer capacitance were obtained later. Then the Pspice A/D (analog/digital) simulator and MicroSim design manager software (MicroSim Corporation) were applied to simulate the equivelant circuit with a pulse switch. Figure 2

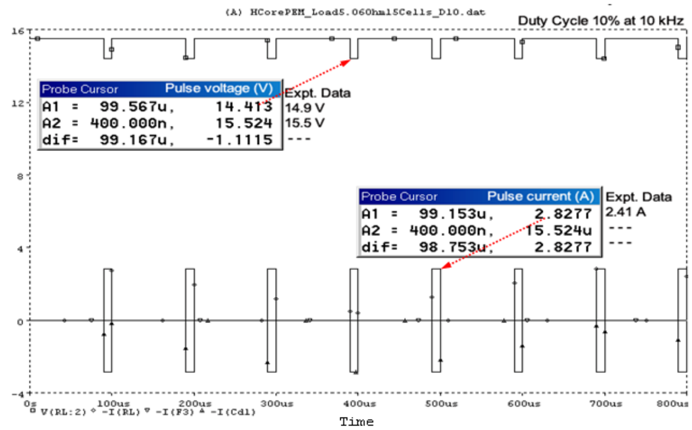

Figure 2. PSpice simulation through pulse equivalent circuit diagram of a 15-PEM-cell substack in the HCore-500-2 system at a pulse load of 5.06 Ohm.

shows the simulated results in comparsion with the tested results in a 15-PEM-cell substack in the Hcore-500-2 system. The data in the circuit were basically identical with the experimental values. The error comes from the contact resistance and the most simplified equivalent circuit diagram.

The further work focused on the Nexa™ power system. A more complicated equivelant circuit model was developed and applied to the Pspice simulation process. The experimental data were also obtained from the lab test at the same temperature as the AC impedance data.

From AC impedance data collected at different currents, the rate limiting behavior of various components and physical processes are also determined by separation of the electronic devices from the fuel cell system. Results are analyzed and compared between the circuit elements and physical processes determined via AC impedance and independent measurements of these same elements by other means. For the Nexa™ PEFC stack with the embedded controller, AC impedance data were in-situ measured. The equivalent circuit model takes the cathodes, electrolytes, and anodes into account. The PSpice results are included in the coming presentation. Through the constant current load (galvanostatic method), the tested direct pulses toward the fuel cells are shown in Figure 3. The PEFC system shows a stronger pulse capability at a high current level of 35 A (estimated *ca.* 291.7 mA cm^{-2}) and *ca.* 65°C in comparison with the lower current levels at lower temperatures. The results from the pulse equivalent circuit using AC impedance technique and PSpice A/D analog or digital simulation stimulate the real time evaluation of the PEM fuel cell(s) and give us better understanding of the physical/chemical processes in the pulse power system.

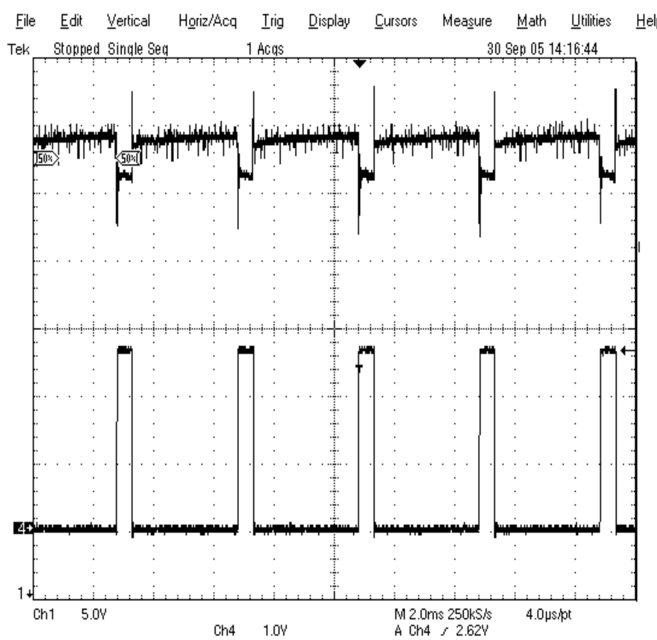

Figure 3. Pulse current (bottom) and pulse voltage (top) at 250 Hz frequency and 13.75% duty cycle applying a constant pulse current of 35 A in the circuit. Nexa™ stack before pulse test: stack temperature, 65°C; stack power, 1214 W; stack voltage, 30.97 V, power output, 986 W; current output, 35 A (~291.7 mA cm^{-2}).

References

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