

VII.K.5 Demonstration and Evaluation of Fuel Cell Powered Trailer Refrigeration Units (TRUs)

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Objectives

- Characterize the emissions, power requirements, and operating conditions of the trailer refrigeration units (TRUs) in the U.S.
- Demonstrate the use of a fuel cell auxiliary power unit (APU) as a power source for a TRU. The demonstration is to be carried out in the field.
- Original plan was to purchase a solid oxide fuel cell (SOFC), however we have built and tested a hybrid proton exchange membrane (PEM) APU.
- Develop a complete simulation model of the TRU and APU system for the different APU types, such as diesel engines, PEM fuel cells (PEMFCs), and SOFC fuel cells.
- Study the possibility of using DC power systems with scroll compressors in the operation of TRUs.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- E. Compressors/Expanders
- F. Fuel Cell Power Systems Integration
- G. Power Electronics
- J. Startup Time/Transient Operations

Technical Targets

This project is focused on assembling and demonstrating an APU system for a TRU that consists of a hybrid PEMFC with power electronics for TRU systems. The project will involve the development of a dynamic systems simulation model of the APU/TRU system. We expect to meet the following DOE 2010 APU/Portable Power targets:

- We have tested our hybrid system, and it can achieve a “Specific Power” of 57 W/kg with the use of lithium ion batteries and 22.8 W/kg with lead acid batteries.

- The power density of our system varies between 27 and 14 W/L depending on whether lithium ion or lead acid batteries are used.
- Our system has been bench tested and the efficiency at rated power varies between 30 and 40 percent. This efficiency applies to power outputs from 5 to 20 kW.
- Our hybrid system with PEMFCs and batteries has a cold start capability of minutes and the number of cycles is in the hundreds.
- At the present time, PEMFCs from Ballard have a warranty of approximately 2,000 hours.
- The startup time for our system is less than 5 minutes.

Approach

- Analyze and design of PEM APU for a TRU system
- Develop and test subsystem components
- Perform system integration and packaging
- Perform integration with TRU vehicles

Accomplishments

- Testing of TRU system with both the diesel engine and electrical power
- Integration of PEMFC and power electronics
- Development of a hybrid APU with battery storage
- Bench testing of APU/TRU system
- Development of dynamic systems model for APU/TRU system

Future Directions

- Bench test APU/TRU system under simulated TRU cycle
- Demonstrate APU/TRU system in the field with TRU heavy-duty vehicles
- Conduct a systematic optimization of the fuel cell APU system with dynamic system analysis

Introduction

During the first year of our contract we have built a hybrid fuel cell power system to power a TRU. At the present time we are testing the equipment and we are in the process of assembling the parts needed to carry out a demonstration on a TRU that is powered by our hybrid fuel cell system. The four major components of our system are the following:

- A TRU system has been delivered and tested, and this TRU is capable of being powered by both a diesel engine and an electrical motor.
- A fuel cell power system has been built and tested to supply electricity to the TRU through a hybrid power supply system.

- A power electronics package has been built and tested, and this electronics package supplies the 3 phase and 240 volt power needed by the TRU electrical motor.
- A hybrid battery storage system has been built and tested, and this storage system was needed to increase the power supply level of the fuel cells.
- A simulation model of a TRU operating with various types of APUs and power electronic systems has been developed.

Approach

At one time in our planning for this research project we had hoped to purchase or receive a SOFC as a gift. Although we have spent countless days in discussions, and we have been promised a delivery of a SOFC, it does not appear that the SOFC will arrive

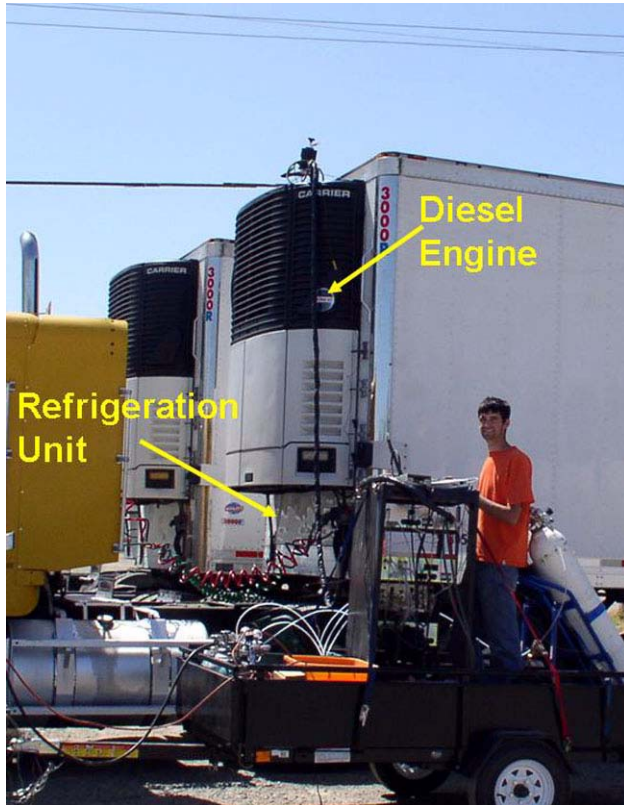


Figure 1. TRU Supplied by the Carrier Corporation for Testing and Demonstration

in a timely fashion. At the present time we have a delivery date of January 2006 - if at all; however, we do not have any detailed information or specifications for this fuel cell. Even if the SOFC arrives in January 2006, it will take months to test and document the performance of the SOFC. Also, it will take a considerable amount of time to integrate the new SOFC into a portable system to power a TRU.

Despite the handicap to our project we have adapted very well, and we expect to meet all the projects goals with our hybrid PEM APU. In fact, since the hybrid APU can reach power levels much higher than the 5 kW SOFC, we will be able to demonstrate our system on a much larger variety of TRU systems. A summary of the approaches we have used are the following:

- Analyze and design of PEM APU for a TRU system
- Develop and test subsystem components
- Perform system integration and packaging

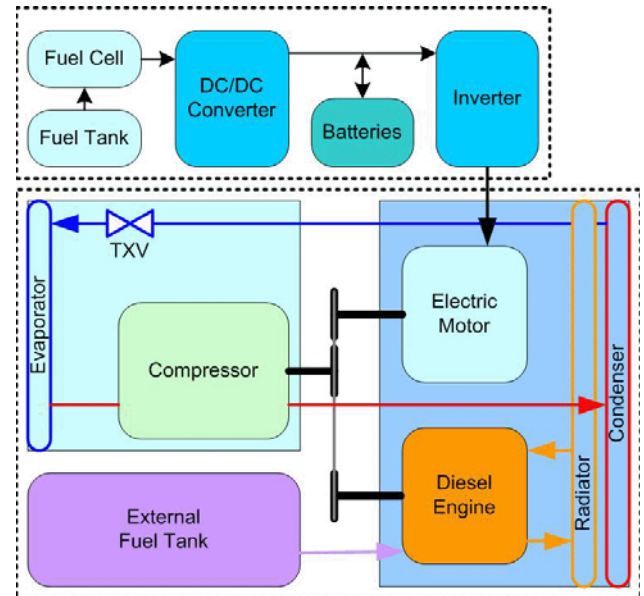


Figure 2. Schematic Diagram of Integrated Hybrid APU and TRU System

- Perform integration with TRU vehicles

Results

Shown in Figure 1 is a TRU system similar to the one that has been delivered and tested by the University of California, Davis (UC Davis). The TRU was successfully tested three ways: (1) with the onboard diesel engine; (2) with 3 phase-240 volt wall power; and (3) with 3 phase-240 volt power supplied by the hybrid fuel cell power system. A block diagram of the overall system is shown in Figure 2, and the individual components that we have built will now be described.

The specific details of the overall hybrid fuel cell system are shown in Figures 2 and 3, and it can be seen that the primary power supply is two Ballard Nexa fuel cells that are rated at 1.5 Kw each. These fuel cells do not have enough power to run the TRU at all power levels, therefore we have a hybrid system with additional battery power. This system design allows the fuel cells to charge the batteries at maximum efficiency, and to power the TRUs which need significant more power supplied than the fuel cell themselves can provide.

Shown in Figures 4 thru 6 are some of the individual components that appear in the diagrams of

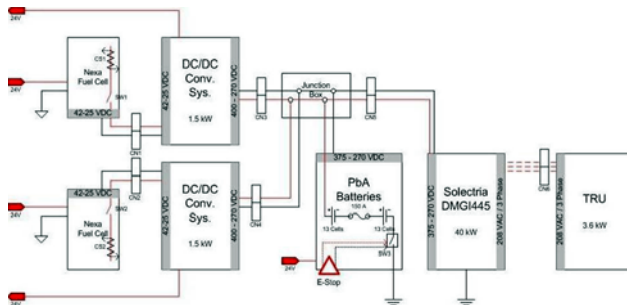


Figure 3. Detailed Diagram of Integrated Hybrid APU and TRU System

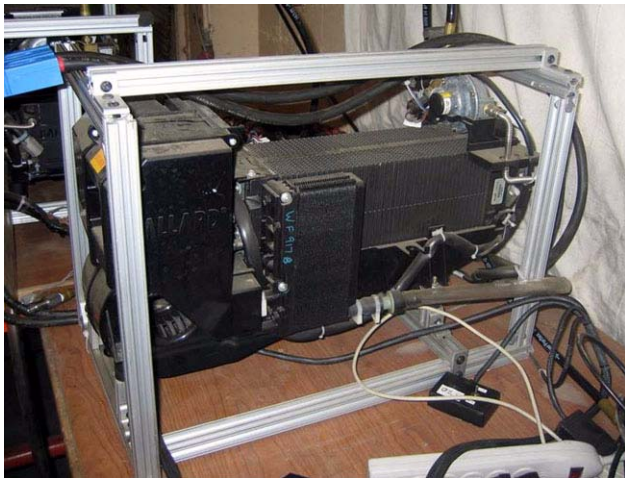


Figure 4. Ballard NEXA PEMFC Utilized for the APU

Figures 2 and 3. The specific details are the following: Figure 4 - A Ballard Nexa fuel cell; Figure 5 - The assembled battery system for the hybrid fuel cell system; and Figure 6 - The DC/AC Inverter to supply the 3 phase-240 volt power to the TRU. As has been previously mentioned, we have powered the TRU successfully in the laboratory with the UC Davis hybrid fuel cell system.

The next phase of the research project is to further test and document the hybrid fuel cell system's performance and to assemble the system on a trailer for demonstration. The projected time schedule for the assembly and demonstration of our hybrid fuel cell system is to start September 2005 and continue through June 2006.

Summary

A summary of the progress and conclusions that we have obtained are the following:



Figure 5. Battery Pack System used in the Hybrid Power Supply



Figure 6. DC to AC Power Converter Used to Supply Power to the APU

- Detail testing of a TRU system with both the diesel engine and electrical power
- Integration of PEMFC and power electronics appropriate for TRUs

- Development of a hybrid APU with battery storage
- Bench testing of APU/TRU system
- Development of dynamic systems model for APU/TRU system

FY 2005 Publications/Presentations

1. Dwyer, H., Brodrick, C., Mader, P., Grupp, D., and Kulkarni, C., “Effect of Engine Size, Operating Mode, and Ambient Temperature on Emissions, and Fuel Economy from Trailer Refrigeration Units”, Annual Meeting of Air and Waste Management Association, Paper 566, June, 2005.
2. Grupp, D., Forrest, M., Mader, P., Brodrick, C., Miller, M., and Dwyer, H., “Development of a Retrofit Fuel Cell Auxiliary Power Unit for Truck Idle Reduction”, SAE Paper 2004-01-2629, Book Number SP-1910.