JP-8 Fuel Cell Powered Electric Vehicle and Generator

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Abstract

This paper summarizes development and demonstration of a JP-8-fueled Fuel-Cell Electric-Vehicle that offers silent-mobility, silent-watch, and export-power as well as a JP-8-fueled Fuel-Cell Generator – both developed with DoD support. The core design consists of a Solid Oxide Fuel Cell (SOFC), balance of plant components, an onboard multi-fuel reformer, and an integrated sulfur trap for processing JP-8. It does not require on-board hydrogen storage. In this paper, the results from evaluation of the 1-kW and 10-kW SOFC prototype systems will be presented. This will include system performance, transient and steady state data, thermal cycling data, power conditioning, and packaging constraints. The advanced SOFC generator combines multiple innovations. This paper will also highlight the system characteristics relating to sulfur cleanup, water balance, and stack performance. We will discuss performance metrics with respect to objectives and thresholds for system fielding, which include start-up, shutdown, user interface, and maintenance requirements.

Keywords

Solid oxide fuel cells (SOFC); JP-8; electric vehicle; generator; silent; MIL-SPEC power; Battery hybridized; high efficiency; low-carbon.

Introduction

JP-8 fueled power generators that can operate silently, with low thermal signature and much more efficiently than conventional generators not only offer expanded capabilities for the DoD but also reduce carbon footprint. The sulfur in JP-8 has been a hurdle for developing practical solutions. The system design developed for the present applications uses a sulfur filter capable of operating with JP-8 containing up to 3000 ppm sulfur. Field operation also requires robustness to exacting environmental conditions and use.

Precision Combustion, Inc. (PCI) has developed standalone Solid Oxide Fuel Cell (SOFC)-based power generation systems (with F-24/JP-8, Sasol IPK, etc.). The systems include fuel reformer, sulfur cleanup, power electronics, water recovery, start/tail-gas burners, heat exchangers, balance of plant components, controls, and packaging. Systems have been developed for various applications and platforms. Electrochemical power generation, without moving parts, is a potential disruptive development.

Electric Vehicle

The prototype was fueled with MIL-SPEC JP-8 and can potentially be operated with other logistic fuels. This 10-kW onboard system included all components required for standalone operation. It was hybridized with a rechargeable battery for startup, peak loads, and load following. Water neutrality and silent operation (i.e., ~60 dBA at 1-meter) was confirmed. The power produced was sufficient for vehicle propulsion and export power. Both 28-32 VDC and 110 VAC for charging batteries and supporting external load demands (for off-grid vehicle charging) were available onboard. Initial off-road demonstrations were conducted at PCI and Detroit Arsenal.

A photograph of the battery hybridized SOFC vehicle prototype delivered to the US ARMY DEVCOM GVSC is shown in Figure 1. A semi-autonomous, off-road vehicle, Squad Multipurpose Equipment Transport (SMET), was chosen for this demonstration. It is designed to lighten infantry soldier load by carrying an array of supplies and gear. It was developed by General Dynamics Land Systems (GDLS). The original vehicle was used as a mule for the prototype developed at PCI. The original vehicle only had a rechargeable battery which required charging from an external power source. PCI's prototype does not require external charging during operation, was designed for 10 kWe export power, and is fueled by F-24/JP-8. It is analogous to a plug-in hybrid, but without the range anxiety.

Figure 1. F-24/JP-8 fueled, electric SMET prototype developed at PCI with US ARMY DEVCOM GVSC support. It is self-charging and provides 10-kWe export power.

Generator

A 1-kW JP-8-fueled Fuel-Cell Generator prototype was also demonstrated (Figure 2). It was suitable for quiet, portable micro-grid compatible operation for stationary and auxiliary power units. It offers improved combat capabilities and meets the single-fuel forward concept. The prototype was successfully demonstrated with field communication equipment. Stable operation over 1,500 hours and over 20 start stop cycles was demonstrated. Designs targeted for MIL-SPEC compliance, improved system weight and efficiency are being advanced.

Figure 2. 1.2 kW JP-8/Diesel fueled SOFC generator prototype developed with USTRANSCOM support.

System Performance

The EV produced up to 10 kWe of variable/continuous electrical power. The generated power was used to charge onboard batteries, power external components (i.e., user load), and support BOP requirements. During vehicle operation, rapid transient demands (e.g., acceleration and turning) were managed via battery hybridization. Instantaneous demands to 15 kWe, necessary to execute vehicle maneuvers, were seamlessly provided by the battery/fuel cell hybrid setup. Vehicle demonstrations (stationary and mobile) were completed at PCI facilities as well as at Detroit Arsenal and Camp Grayling. The 1.2 kW SOFC generator was demonstrated for the US Transportation command at MacDill AF base in Tampa. Ability to power communication equipment was confirmed. Thermodynamic considerations were used to direct system optimization via CHEMCAD process simulation software. It was used to identify components specifications and achieve high system efficiency via effective thermal and flow balancing.

The power conditioning system was developed to provide output control (maintain required voltage range and power quality to the electrical loads), charge management of hybridized batteries, and fuel cell stack protection from overload, current surge, ripple, and load distortion. This feature not only allowed hybridization with MIL-SPEC rechargeable batteries but also included flexibility for microgrid integration and direct battery charging. Battery hybridization for load balancing and maintaining power quality required development of custom algorithms and hardware for matching load and fuel cell transients.
Effectively packaging within the SMET vehicle of the fuel reformer, sulfur filter, fuel cell, and associated components to account for efficient flow, thermal integration, and space claim management was critical towards meeting form factor requirements. This includes separation of hot and cold zone components, designing for shock, vibration and environmental conditions, resistance to electrical interference, and manufacturability. Multiple iterations were performed to optimize the packaging. Finite Element Analysis of the primary components was completed to determine the structural strength and requirements for the enclosure frame and supporting hardware and vibration testing to meet the packaging requirements. This analysis was used to identify the required materials of construction and thickness to support the components, sub-systems, and the complete fuel cell system and source vibration isolators, tailored for the SMET vehicle.

Conclusions

An F-24/JP-8 fueled, fuel cell based, electric-semi-autonomous vehicle was developed and successfully demonstrated. It was able to achieve strategic benefits of silent-watch, silent-mobility, and MIL-SPEC quality export-power with standard logistic fuels. This was the first demonstration of a long-envisioned goal and highlighted the potential of using a "solid state" power generation technology for a range of DoD applications, including auxiliary power, propulsion, unmanned platforms, portable generators, sensors, etc. This advance has also generated considerable commercial interest and non-military applications are being advanced as well. Transition to fielded applications will require significant work to address manufacturing and operational requirements. Importantly, MIL-SPEC requirements, cost optimization, weight and size reduction, fast start, long-term durability, etc. are required for widespread implementation.

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