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# Marine Molten Carbonate Fuel Cell Demonstration Module

USCGC VINDICATOR Ship Interface Studies

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**16. Abstract (MAXIMUM 200 WORDS)**


In this study, the U.S. Coast Guard (USCG) investigated the impact upon CGC VINDICATOR ship systems resulting from potential conversion to fuel cell propulsion and auxiliary power. VINDICATOR is a T-AGOS class monohull, 224-feet in length, powered by four Caterpillar diesel-electric generators with DC propulsion motors. USCG selected this vessel as a candidate for development and potential demonstration of fuel cell power on board ships. Space and weight limitations and marine operational requirements uncovered during this study are believed to be applicable to other ship installations. Detailed changes to structural, electrical, fuel delivery, exhaust management and related systems necessitated by removal of the four main diesel generators and replacement by four molten carbonate fuel cell modules were developed. Also developed was the outline design of each 625 kW molten carbonate fuel cell Demonstration Module, including fuel processing, fuel cell stacks, and inverter. A dynamic computer simulation model was created which linked the fuel cell performance to ship parameters including displacement, speed, and loading cycles. This information was used to analyze the ship integration impacts based on the fuel cell design. Included with this final summary report are outline figures of detailed removal and installation drawings detailing existing and proposed arrangements.

Several conclusions are made. The proposed fuel cell modules are compatible with existing ship interfaces, with relatively minor modifications. The fuel cell modules are substantially larger than the diesel generators they replace, necessitating removal of the non-structural side shell within the main diesel generator room. Existing air handling, exhaust, and fuel delivery systems can be reused, ship performance (stability and seakeeping) is unchanged, and minor maneuvering performance changes may result. Increased range is expected due to the predicted higher efficiency of the fuel cells. Overall, the installation and operation of fuel cells on this ship appears to be technically feasible.


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# EXECUTIVE SUMMARY

In this study, the U.S. Coast Guard investigated the impact upon CGC VINDICATOR ship systems resulting from potential conversion to fuel cell propulsion and auxiliary power. VINDICATOR is a T-AGOS class monohull, 224 feet in length, and powered by four 600 kW Caterpillar diesel-electric generators with DC propulsion motors. The USCG selected this vessel as a candidate for development and potential demonstration of fuel cell power on board ships. However, space and weight limitations and marine operational requirements uncovered during this study are believed to be applicable to many other future ship installations. Detailed changes to structural, electrical, fuel delivery, exhaust management and related systems necessitated by removal of the four main diesel generators and replacement by four molten carbonate fuel cell modules were developed.

A conceptual arrangement of the machinery space and interfaces with auxiliary systems was developed. The volume of the fuel cell system was more than two-and-a-half times that of the generators they replaced. The larger dimensions, length, height and width of MC fuel cells compared to diesel generators, require modifications in the machinery room. In particular, removal of the void bulkheads on both sides of the machinery room is required in order to provide access to the four fuel cell modules. The machinery service systems, seawater, lubrication oils, fresh water, fuel and compressed air are all affected, although to a relatively minor degree.

Since the fuel cells' weight and center of gravity were similar to those of the generators, the ship's performance in terms of stability and sea keeping are expected to remain unchanged. Limited maneuvering simulations, ship forward acceleration and reversing, were performed. These simulations showed that the application of power produced by fuel cells is expected to cause insignificant changes in the maneuvering performance of the ship.

The power generation and distribution systems for the ship were originally designed to comply with the Type 1 power requirements of DOD-STD-1399, Section 300. This DOD standard requires diesel generator sets to comply with the transient load requirements of MIL-G-21296 and MIL-G-21410, and to ensure that the system power quality is maintained during large load transients. Molten Carbonate Fuel Cells do not fully comply with these criteria. With the current load limiting features inherent in the propulsion system drive controls, the transient response from the currently designed fuel cells is expected to perform well for ship maneuvering power requirement. However, similar to most advanced, highly turbocharged diesel generators, the short term transient response does not fully support the requirements of DOD-STD-1399 or the IEEE-STD-45 equivalent. Steps to enhance instantaneous transient response can be incorporated into either the consumer side, or the fuel cell system itself. These can include incorporation of energy accumulators or capacitors in the system. A similar problem occurs with automobiles where improved acceleration is achieved by adding turbochargers to small engines (in terms of cylinders and cylinder size) or by using multiple power sources such as adding electric battery driven motors to the power system.

This final report also provides the technical summary of the Dynamic Simulation Model (DSM) development for the Molten Carbonate, Coast Guard Fuel Cell (MCFC) power plant. It lays the foundation for computer programs and software coding of the DSM and incorporates the vessel's electric propulsion system as a controlled large load typical to ships with an integrated electric propulsion system. A narrative description of the MCFC power plant operation and control strategy is also provided. The governing transient equations related to the fuel cell and the fuel processing are described in detail in the Dynamic Simulation Model (DSM).

The conversion of the power generation system of the USCGC VINDICATOR appears technically and physically feasible. There is sufficient volume and surface area to accommodate equal power Molten Carbonate fuel cells. The interface to the ship's systems is technically feasible.

The impact upon performance is, however, noticeable. Higher thermal efficiency, significantly better part load performance, increasing endurance (range), and reduced vibrations, noise and emissions outweigh the non full-compliance with short-term transients. This is especially true in light of the trend to diesel generator (DG) or turbo-generator (TG) powered ships. This trend has been seen in current designs of cruise ships and U.S. Navy ships for vessels for coastal warfare, in a partial load loitering condition such as research vessels, or where thermal emissions are critical.