Development of a 13kW Fuel Cell based UPS System

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1. Abstract

PEM fuel cell stacks were integrated with an Uninterruptible Power Supply (UPS) system producing a viable solution to the increasingly unreliable utility infrastructure. Fast-switching, feasibility, and economic issues were examined that showed how fuel cells can support the new UPS power architecture for extended runtime applications.

MER has designed and demonstrated a 13 kW fuel cell based electrical generator with 3-phase electrical output of 220 V AC for UPS applications. Two 6.6kW fuel cell stacks have been designed and integrated with an inverter for quick transfer of electrical power between utility power and the fuel cell.

2. Overall Module Design

A 13 kW PEM fuel cell system was designed and developed for an exceptionally fast transient response time, high efficiency, low cost, and extra ruggedness. This system has two stacks connected in series generating 132 DC Voltage. Each stack consists of 66 cells and delivers up to 6.6kW at 0 psi and 85W at 5 psi. The supporting systems for MER's 13kW fuel cell generator may be categorized into three main sub-systems. These are control, monitoring, and the supply of hydrogen, oxygen, and coolant. All control electronics that supports the recirculation systems were designed by MER. All necessary supporting power electronics are included in the system. Closed-loop hydrogen, oxygen, and coolant recirculation systems were developed and integrated. This closed-loop gas recirculation system facilitates nearly 100% fuel and oxidant efficiencies. It also serves to supply humidified gas to the system, eliminating the need for a separate complicated, high-cost humidification system. A DC fan attached to the heat exchanger at the face of the unit controls the stack temperature during peak load.

National Instruments LabVIEW development software was used at MER to write a program that controls the system hardware and enables advanced measurements of system parameters. The UPS unit (Powerware 9330, 40 KVA) was obtained from Powerware. Powerware supplies 90% of the major installed UPS assets to the Air Force. Therefore, MER integrated Powerware inverter for the 13 kW fuel cell system. The input voltage of the Powerware unit is between 240 and 338 V DC. MER installed a DC-DC converter to increase the fuel cell voltage from 132 V DC to 336 V DC. MER developed and installed a sophisticated interface between the fuel cell and the UPS unit. The interface is capable of supplying power during the transition time between grid failure and fuel cell switching. During this transition time, the fuel cell system will come online and begin delivering power.

3. Integration and testing of 13 kW Fuel Cell UPS System

MER's objective was to develop and commercialize the system. The system should be efficient and able to operate using hydrogen and oxygen under pressure. As a part of the commercialization of the fuel cell system, MER has been working to reduce the cost while improving the power density of the stack. A new sealing concept for the flow-field plate was developed wherein the custom-designed groove in the bipolar plate in which a thin rubber gasket is embedded. Anodized aluminum was used for the end plates. Gold plated copper sheet was used for the bus plate. Each stack has separate water storage tanks, water circulation pumps, and heat exchangers. All components are specifically optimized for the lowest possible cost. There is no external humidification system and no complex high-pressure controls. The heat exchanger with two DC fans at the face of the generator controls the temperature of the cooling water loop and the inside of the unit. Each stack is equipped with two electrical leads, four gas connections and two water connections. The stacks can be exchanged if necessary. The stacks are water-cooled. Excess heat is rejected through the heat exchanger at the end of the unit.

An initial packing and assembly concept for a Fuel Cell UPS system was designed. To obtain easily stackable units, all openings, connectors, and controls have been placed on the top, bottom, and outward faces of the stacks. The generator has two compartments. Each compartment has one stack. The designed 13 kW Fuel Cell UPS system has a capability to use batteries if the switching time of the fuel cell does not meet design targets. These batteries are smaller than the current Powerware batteries, and are used for hold up times of approximately 30s to 1 minute to allow the fuel cell to come online from a cold start. However, it is still our design goal to not require these batteries by running the fuel cells in hot standby mode 0(constant fuel cell operation, very low power consumption). This will keep the fuel cell hydrated and ready for a rapid switch over in case of grid power failure. Figure 1 shows the MER's 13 kW Fuel Cell based UPS generator. All necessary parameters such as the stack efficiency, fuel consumption rate, and heat and water production rates for the 132-cell stack were calculated. The hydrogen and oxygen consumption rates are proportional to the gross fuel cell current demand and nearly proportional to the net output current delivered. The efficiency of the 132-cell stack at 0 psi and 5 psi was calculated as a function of net output current and net output power, which is shown in Figure 2. The stack efficiency is defined by the ratio of net output power to the lower heating value of hydrogen consumed in the fuel cell reaction. The maximum stack efficiency at 5 psi was observed to be 58% at close to zero power and nearly 40% at full power. However, the system efficiency is high where as it includes the extra DC-DC boost to convert 132 V to 336 V to use the Powerware UPS in the system.

Fig.1: MER's 13 kW Fuel Cell UPS system.

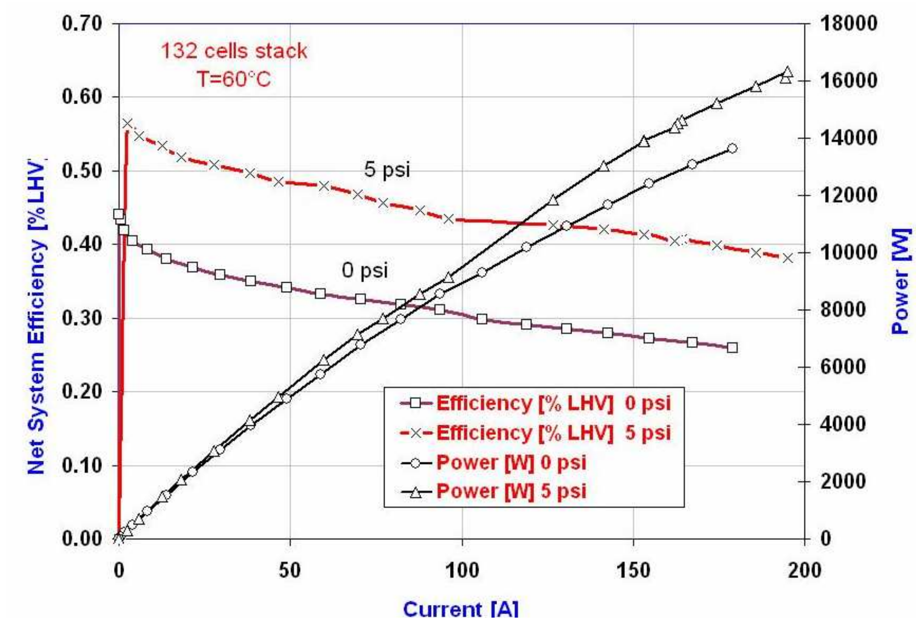

Fig.2: Efficiencies of the 132-cell stack operated with hydrogen and oxygen at 5 psi and ambient pressure.

3.1 Fuel Cell Load Switching Behavior Test

The fuel cell stacks are designed to provide power indefinitely, as long as there is fuel. To know the capability of the fuel cell, load switching behavior was measured using the Trip-Lite inverter to switch between grid and fuel cell power. This study was purposely conducted in order to know the response time of the fuel cell based generator. The measured response time to load switching from grid to fuel cell operation was less than 1.9 ms and was completely transparent to a computer's CPU. A digital real time oscilloscope (Tektronix TDS 210) with nanosecond resolution was used. Figure 3 shows this response as the stack OCV drops from 42.9 V to 40.2V with the application of an approximate load of 550 Watts.

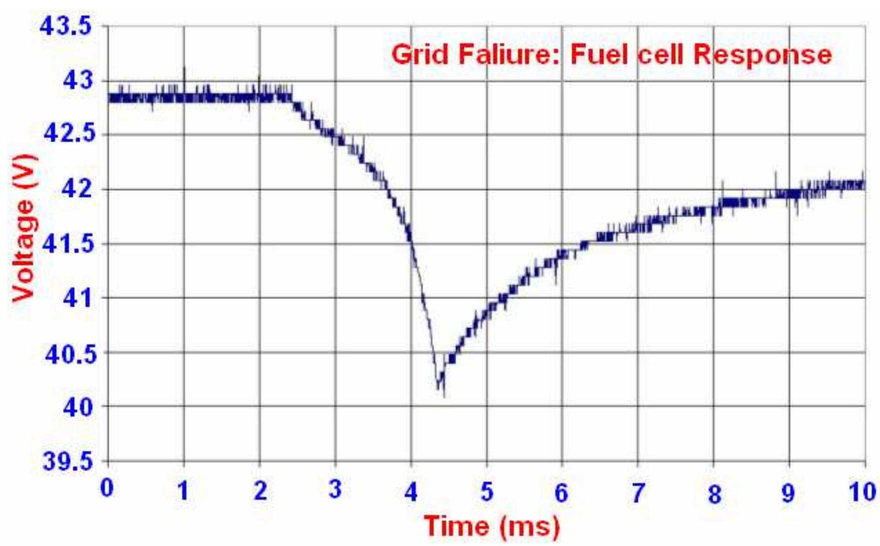

Fig.3: The load switching response time from the fuel cell to the grid.

3.2. Fuel Cell –Electrolyzer-UPS System

MER has developed a closed-cycle electrolyzer that produces hydrogen and oxygen using fuel cell product water and grid power while the fuel cell UPS is idle. This electrolyzer is used to refill the hydrogen and oxygen tanks after a generator load cycle, completing the regenerative cycle. When grid power fails, the fuel cell UPS takes over power production, depleting the hydrogen and oxygen stores and producing water. When grid power is restored, the electrolyzer engages and splits the collected product water into its composite gases, which are stored in pressurized tanks against future demand by the UPS. The electrolyzer is noiseless except for the compressor pumps used to store the gases.

4. Net Power and Parasitic Loss

The net power and parasitic losses of the 13 kW fuel cell UPS system including fuel cell stacks and balance-of-plant components were calculated. Parasitic loads from the water pumps, cooling fans, and other subsystems were low, totaling about 1.25% of the fuel cell power output. The net DC power and the parasitic loss was calculated, which comes to about 200 Watts. The parasitic loss of the AC power operation of the 13kW Fuel Cell UPS system was calculated. The parasitic loss of the control electronics was 200 Watts. The efficiency of the first DC-DC converter (boosts from 130V DC to 336 V DC) was 85%, which comes to about 2400 Watts loss. The efficiency of the Powerware DC-AC conversion was 90%, or 1600 Watts loss. Figure 4 shows the net DC and AC power generation of the 13kW Fuel Cell UPS system.

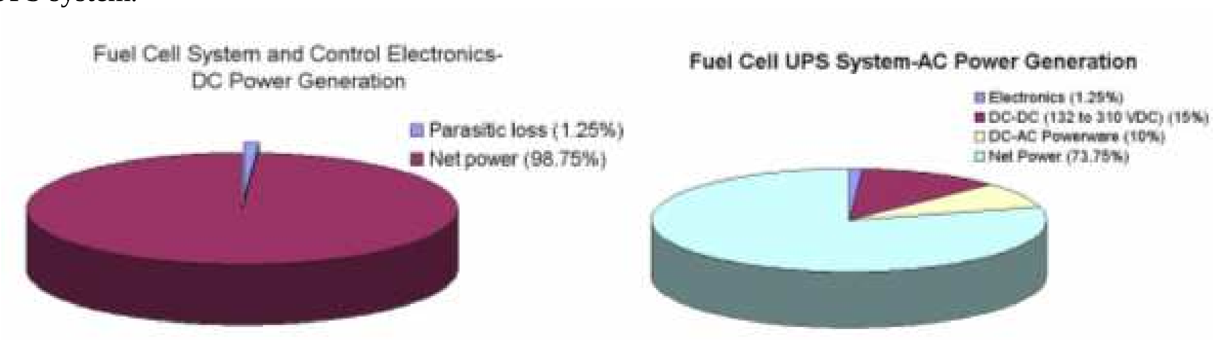

Fig.4: Net DC and AC power and parasitic losses of the 13kW Fuel Cell System excluding UPS losses.

The breakdown of the cost of MER's stack was calculated excluding the labor costs. The cost of operation at MER for the fuel cell generator was determined to $1.25 per kWh based on the current real purchase price of hydrogen and oxygen tanks, which are $21.80 and $13.67, respectively. This cost only considers the fuel consumption and does not take into account the initial cost of the generator or maintenance costs.

5. Conclusion

The viability of the Fuel cell based UPS system for single and three phases was demonstrated. MER is currently reducing the cost of the components, and expected to be commercialized in the close near future.