The 22nd Conference of Mechanical Engineering Network of Thailand
15-17 October 2008, Thammasat University, Rangsit Campus, Pathum Thani, Thailand

Development of a Standalone PEM Fuel Cell System for Search and Rescue Operation

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Abstract

Prototype of standalone PEMFC system developed as a search-and-rescue power generator unit is currently under development at Automation and Mechatronics Laboratory, National Metal and Materials Technology Center. This paper presents a system design and on-going results of the development. The system operates at normal net output power of 300 watts can reach maximum net power of 400 watts. The final system encloses a 760-litters air shippable hydrogen storage that will allow the unit to be pre-fueled and ready to be air shipped for operations.

Keywords: fuel cell, clean power generator, fuel cell control

1. Introduction

Fuel Cell is an energy conversion technology that converts hydrogen fuel directly into electricity through electrochemical process without combustion or mechanical work involved [1-2]. It has been successfully implemented in several critical operations such as space exploration, and is currently emerging as clean and efficient technology for transportation and portable power generator devices. Advancement in PEMFC technology enables us to build lighter power generator unit for search-and-rescue operation that can work at low operating noise level i.e. not to hinder a search operation comparing to the IC engine power generator. Its high energy density comparing to battery pack allows the system to work continuously for long hours.

Fig. 1 shows basic principle of PEM fuel cell system. A membrane in the middle is impermeable to gases but can conduct protons. The membrane coated with catalyst is compressed between two porous and electrically conductive electrodes and two current collector plates allowing reactant gases to flow through as well as allowing electricity to be drawn out. Electrochemical reaction occurs at the surface of the catalyst particle typically platinum at the interface between electrolyte (electrode) and the membrane. Hydrogen molecules fed into the interface through the flow channel are spitted into two protons and two electrons.

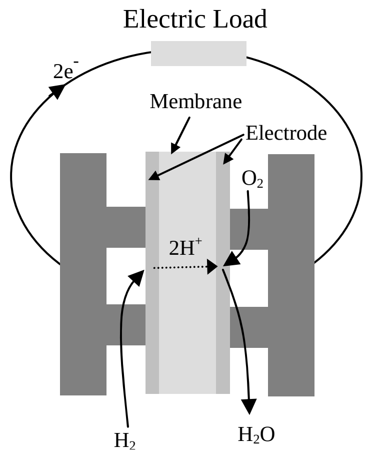

Figure 1 Basic principle of PEM fuel cell

The protons travel through moist membrane, whereas the electrons travel through electrically conduct porous layer, through electrodes, through current collector and through outside electric load and come back to the other side of the membrane. At the catalyst on the oxygen side, the electrons meet with the protons and oxygen. Water vapor is created in the electrochemical reaction.

2. Design Concept

The design concept is to be non-stationary and standalone power generator unit. All subsystems including the hydrogen supply are needed to be encapsulated into a single package to allow easy transport and carry. All subsystems inside the developed fuel cell system are shown in Figure 2

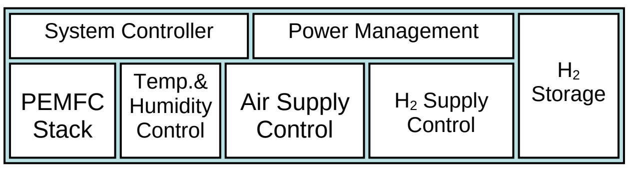

Figure 2 Main components in PEMFC system

All of the above subsystems require synchronization and control to ensure safe operation of the fuel cell stack and allow the system to reach its maximum efficiency. Next section gives details on these control subsystems.

3. PEM Stack Testing

PEM stack used in this system consists of 10 cells with 100 cm^2 effective area in each cell. Stack polarization (I-V) and power curves are shown in Figure 3. Open circuit potential is 9.26 V with maximum current tested reached 71.72 A at 6.26 V resulting in maximum testing power of 449 watts. Thus, the system can run at the nominal operating power 350 watts with around 50 watts used in auxiliary and power conditioning units.

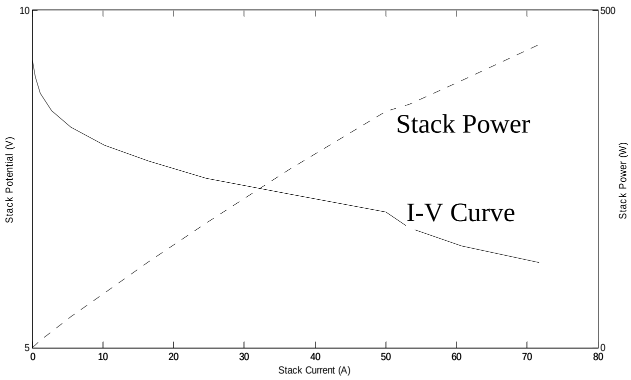

Figure 3 Tested results of the stack polarization and generated power curves used in the system

4. Balance of Plant Control

Balance of plant is a term represents all auxiliary components or subsystems that allow a fuel cell stack to operate properly and safely. These subsystems include stack and reactant gases temperature control, hydrogen flow and pressure control, air flow and pressure control, humidity control and output power management. Performance of these subsystems is very crucial for overall system efficiency and operating life of the stack.

4.1 Stack Operating Temperature

Electrochemical process takes place at the interface between electrode and membrane in the cathode side generates heat and water vapor that must be managed. Temperature control loop is in placed to manage the access heat and control the stack temperature at 70°C (typical Proton Exchange Membrane type fuel cells operate at 60°C -80°C. temperature range).

Water vapor generated in the process is pushed out of the cells with access flow of oxygen. Nevertheless, water content in the membrane must be kept at the right level by adding water vapor at the up stream of the reactant gases to prevent the membrane from drying and eventually damaged. Humidifying the inlet gases can be done at the either hydrogen or oxygen, or both, but based on our closed-end hydrogen flow configuration, we only humidify the inlet air into the stack using FC-Series Multi-Tube Nafion Humidifiers, FC125-240-5M, from Purma Pure. The humidification system uses the humid exhaust air that was pushed out from the stack to added moisture into the inlet air stream. This membrane humidification scheme results in recirculation of water vapor generated in the electrochemical reaction be fed back into the system to humidify the membrane in the upstream.

4.2 Reactant Control

Flow and pressure of both hydrogen and air as oxygen supply are needed to be controlled to reach the required output power and in some cases to prevent PEM stack from damaging due to oxygen starvation [3] and excessive pressure difference between two reactant sides. Air is pushed into the stack using a diaphragm pump widely used in fishery oxygen supply. The air supply flows through a flow sensor and pushed through manifold to measure air inlet pressure before fed into a Multi-Tube Nafion Humidifier and entering the stack inlet. Oxygen must be supplied at the right amount based on the present current demanded from the electric load side. Flow supplied of oxygen and hydrogen can be computed from the stack current supplied to load based on Faraday's Law and molar volume relation as

$$\dot{V}_{H_2} = \frac{RT}{P} \times 1000 \times 60 \times \frac{I_{st}}{2F} \quad (1)$$

$$\dot{V}_{O_2} = \frac{RT}{P} \times 1000 \times 60 \times \frac{I_{st}}{4F} \quad (2)$$

where $\dot{V}_{H_2}$,$\dot{V}_{O_2}$ are hydrogen and oxygen flow rate in L/min, R is gas constant (8.314), F is Faraday constant ($Cmol^{-1}$), P is pressure (Pa), T is temperature (K), and I_{st} is stack current (A). Due to the configuration of the flow (closed-end at the hydrogen side), we apply the formula to the oxygen side by setting the oxygen access ratio to N and assume oxygen content in air at 21%. Thus the air flow rate in L/min as required for stack current I_{st} can be computed by $N \cdot I_{st} / 0.21$, where N (>2) is the oxygen exceed ratio. This air flow is controlled using feed forward path computed using diaphragm pump inverse model plus feed-back error from flow sensor in air flow-through mode. A manual valve is placed at the air exhaust after passing the humidifier to build up pressure in the cathode manifold. Since anode flow is configured as closed-end type, controlling of hydrogen flow based on Eq. (1) might not be the right choice due to the pressure build up. Instead, we control hydrogen inlet pressure to the stack at 130 kPa. Fig. 4 shows all major control subsystems. P represents pressure sensor. T represents temperature sensor. Hydrogen pressure supplying to the stack inlet is controlled through a proportional valve. Hydrogen purging is controlled through normally-closed solenoid valve at the outlet of the stack anode. Air is supplied from a diaphragm pump. Exhaust air recalculated back to add moisture to the inlet air supply. Fig. 5 shows the actual system under development. Size of the system is equivalent to a desktop computer casing with all subsystem incorporated inside. Users can operate the system through a touch screen PLC located at the top right of the system. The space in the bottom left of the system will be equipped with a 760L metal hydride storage tank from Ovonic. Power management unit including converter, inverter, power drive circuits and a batter pack is located behind and underneath the touch screen PLC.

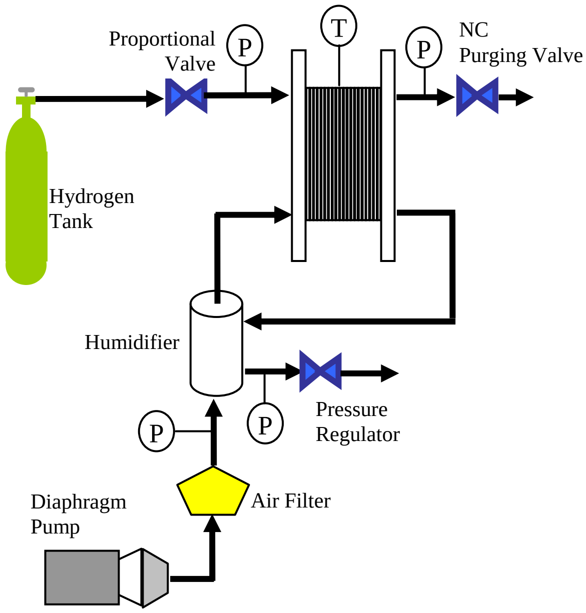

Figure 4 Fuel Cell System with major subsystems

Figure 5 System under development showing all main subsystems

5. Results and Discussion

Some preliminary results of our system are reported in this paper. We test the system by connecting the system to an external load and try to regulate the output power to 10 watts from 0-6 sec. and then 20 watts from 6-14 sec. as shown in Fig. 6 (a). The response power is shown in Fig. 6 (b) exhibiting a surge in power at the beginning when the load was first applied and eventually converging to the desired power. The pressure and flow at the anode side are shown in Fig. 6 (c) and (d) respectively.

The diaphragm pump for air supply used in this system is inexpensive and widely available comparing to more costly and not widely available turbine pump that operate at high speed and commonly used in fuel cell installed in automotive applications. On the other hand, diaphragm pump exhibits some limitation to the flow and pressure demand and produce significant ripple in the air flow channel causing difficulty in air flow control.

Acknowledgment

This research is funded by Alternative Energy Cluster Program, National Science and Technology Development Agency (NSTDA).

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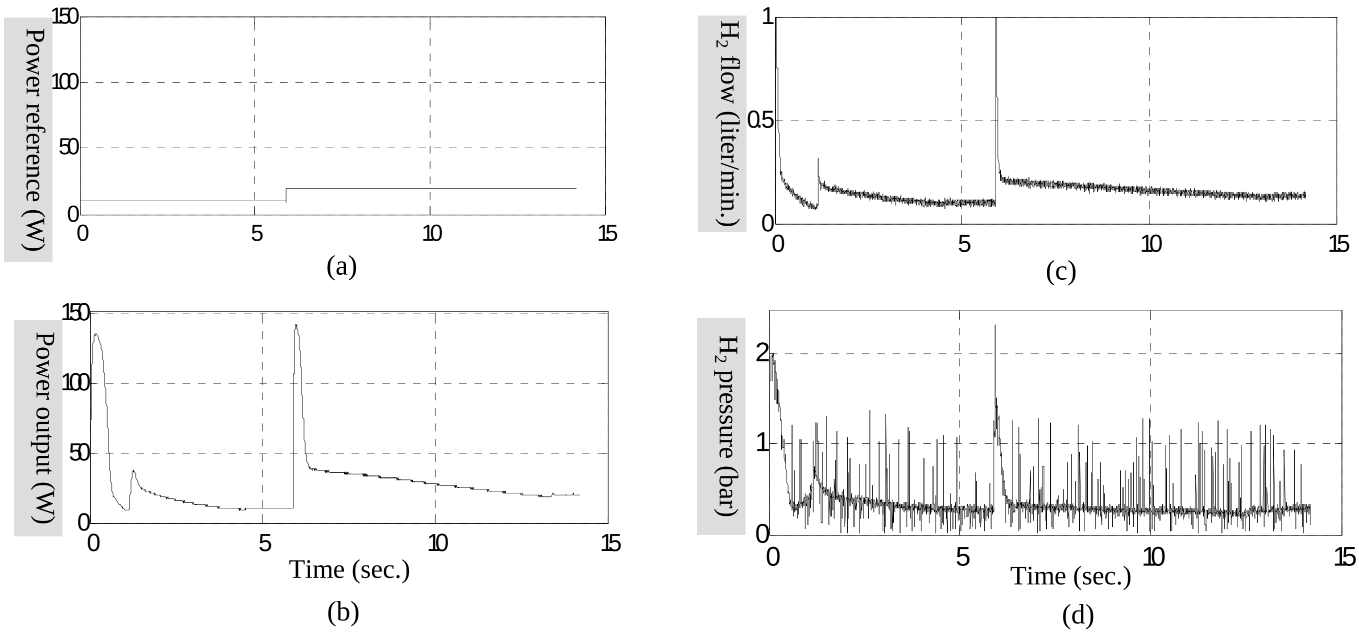

Figure 6 (a) Desired power output (b) Actually power output (c) Hydrogen utilized in the system (d) hydrogen supply pressure