Applied Energy 108 (2013) 184–193

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Thermal control and performance assessment of a proton exchanger membrane fuel cell generator

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HIGHLIGHTS

- Thermal control unit along with a smart algorithm is able to limit the fuel cell temperature in a desired range.
- Thermal control unit comprises a thermostat, a radiator/fan assembly, a coolant heater, and a convection fan.
- The system efficiency is increased with increasing the external load, reaching 46% at 80% load-duty.
- The stack coolant inlet temperature is optimized in the range 58–63 °C.

ARTICLE INFO

Article history:
Received 11 August 2012
Received in revised form 26 February 2013
Accepted 10 March 2013
Available online 9 April 2013

Keywords:
Proton exchange membrane fuel cell
Thermal control unit
Radiator
Thermostat
System efficiency

ABSTRACT

An original-designed thermal control scheme that manages the thermal behaviors in a proton exchange membrane (PEM) fuel cell generator has been proposed. It not only keeps the stack from overheating under extreme high external loads, but also prevents the stack from staying too cold in the cold-start conditions. A thermal control unit (TCU) together with a smart control algorithm is able to limit the fuel cell operation temperature in a desired range. The TCU comprises mainly a thermostat, a radiator, and a heater. It divides the stack coolant into a cooling stream and a heating stream that maintains a pre-set coolant temperature before entering the stack. Parametric studies include the external loads ($0 < P_L < 4$ kW) and the stack coolant inlet temperature (SCIT = 53, 58, and 63 °C). The dynamics of SCIT under different loads are measured to verify the thermal reliability of the fuel cell generator. Then, examining the effect of SCIT on the system efficiency assesses the performance the fuel cell generator. Finally, an empirical correlation for the system efficiency of the PEM fuel cell generator under different SCITs is presented as a function of the external loads.

1. Introduction

Fuel cells convert directly the chemical energy of fuels to electricity through electrochemical reactions. The combination of benefits in high efficiency, eco-friendly nature, and fuel diversity makes them attractive in alternative power conversion devices. Among various types of fuel cells, the proton exchange membrane (PEM) fuel cell is regarded as the potential candidate of the next-generation vehicular propulsion [1–3] and residential power generators [4–9].

In general, a PEM fuel cell produces a similar amount of waste heat to its electrical power output. For example, a PEM fuel cell generating 5 kW electrical power should dissipate 5 kW heat as well. However, PEM fuel cells tolerate only a small temperature variation due to their low operating temperature, typically <100 °C. Therefore, the thermal management of a PEM fuel cell generator has been recognized as one of the most critical technical issues that must be resolved before it can be commercialized [10,11]. As a matter of fact, the temperature inside the fuel cell has a strong impact on the fuel cell performance in consideration of proton conductivity of the PEM, electrochemical reaction kinetics of the electrodes, and transport ability of reactants. Firstly, elevated temperature could enhance the electrochemical reaction kinetics that reduces the activation polarization and also promotes the transport ability of reactants/products that reduces the concentration polarization. Secondly, the proton conductivity in the PEM is temperature and humidity dependent, which mainly determines the characteristics of ohmic polarization. The current popular PEM material, perfluorosulfonic polymers (such as Nafion®), is an excellent proton conductor but only when fully hydrated [12]. Although, elevated temperature could enhance the water–vapor mobility that facilitates the water removal from the electrode and thus avoids electrode flooding [13], the requirement of good hydration of pure Nafion® PEM limits the maximum fuel cell operating temperature to about 85 °C [14]. Moreover, below 0 °C pure Nafion®

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http://dx.doi.org/10.1016/j.apenergy.2013.03.025

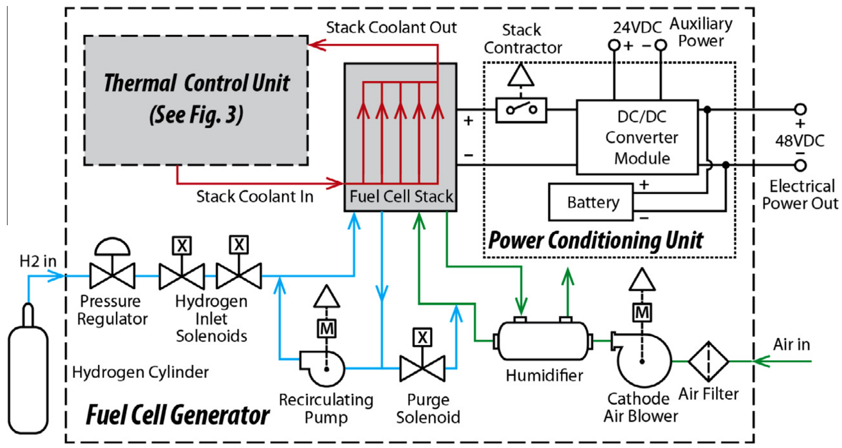

Fig. 1. Schematic drawing of the fuel cell generator.

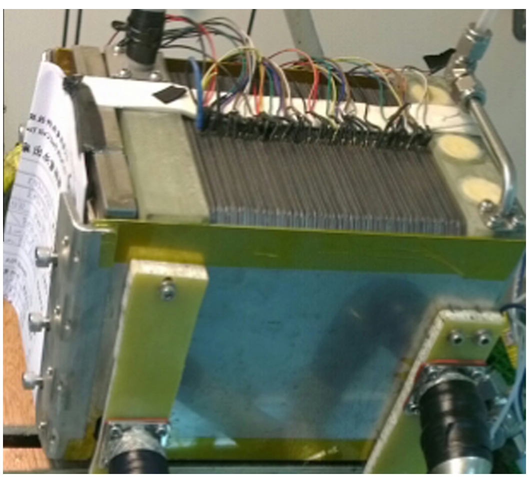

Fig. 2. Photo of the fuel cell stack.

PEM loses its proton conductivity because the water as proton carrier inside freezes. Thirdly, beyond the fuel cell working temperature the component material is likely deteriorated. For example, high working temperature might impose an imbalance of thermal stress on the PEM and the electrodes, which results in a significant contact resistance. In addition, high working temperature will increase the growth rate in the platinum particle size that results in a reduction of catalytic surface area and thus efficiency degradation [15]. The above stringent thermal requirements have presented a significant heat transport problem in operation of a PEM fuel cell system. Therefore, an appropriate thermal control scheme plays an important role in ensuring highly reliable and efficient operations of a PEM fuel cell system, which comes into being the objective of the present study.

In the past decade, quite a few modeling/experimental works have been conducted to study the thermal transports in PEM fuel cells. Most efforts evaluate the thermal characteristics inside stack channels [16–19], cells [20–26], or electrodes [27–34] based on the meso- or micro-scale approach. However, there have been very limited studies on optimizing the fuel cell cooling on a system level, especially for experimental works of a fuel cell generator of large capacity (>5 kW). Therefore, the objective of the present work is to conduct an experimental study to examine the transient electrical/thermal performance in a PEM fuel cell generator cooled by a novel cooling technology. Special attention will be placed on the implementation of an original-designed thermal control unit (TCU) in a fuel cell generator that copes with high perturbation conditions such as startup, quick change in load, and shutdown. The TCU comprises a thermostat, a radiator/radiator fan assembly, a coolant heater, and a convection fan. The thermostat divides the stack coolant into two circuits, i.e., a cooling circuit and a heating circuit. The coolant in the cooling circuit is cooled by the radiator/radiator fan assembly and returned to mix with that circulating through the electrical heater to maintain the coolant temperature at the designed value before entering the stack. In combination of proper control algorithms, it allows for securing safe and efficient operation of the system under strong load variation and prevents the stack from staying too cold in cold start. Parametric studies include the external loads (P_L) and the stack coolant inlet temperature (SCIT). First, the dynamics of stack coolant inlet temperature under different loads are measured to verify the reliability of the present thermal control scheme. Then, examining the effect of SCITs on the system efficiency assesses the performance the fuel cell generator. Finally, an empirical correlation for the system efficiency of the PEM fuel cell generator under different SCITs is presented as a function of external loads. The information provided by the present work could assist the designer in achieving the best thermal management of a PEM fuel cell generator, and also be helpful in identifying the thermal/electrical ratio for a PEM based fuel cell power plant of large capacity for cogeneration.

2. The experiment

2.1. System design

Fig. 1 is a schematic drawing of a PEM fuel cell generator. It consists of a PEM fuel cell stack, an air delivery subsystem ([1]green-line loop), a hydrogen delivery subsystem (blue-line loop), a power conditioning unit and a thermal control unit (TCU). Fig. 2 gives a photo of the PEM fuel cell stack employed in the present work. It is a customized product [2] with maximum power of 5.8 kW. The technical specifications of the stack are listed in Table 1. Table 2 summarizes the components used in the subsystems of the fuel cell generator.

2.1.1. Air delivery subsystem

As shown in Fig. 1, the air delivery subsystem provides filtered and humidified air to the cathode of the fuel cell stack. Fresh air from the ambient enters an air filter that removes solid and gas

[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.