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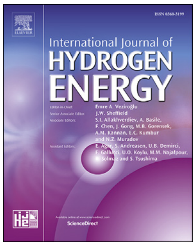

A new approach to online AC impedance measurement at high frequency of PEM fuel cell stack

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ABSTRACT

In the PEM fuel cell system, the water management strategy is founded on the accurate water content estimation while until now it is still a large obstacle that prevents the application in the field of transportation. Focused on this problem, approaches such as the multi-mixture model have been put forward to estimate the water content but there exist some limitations. Some recent literature work shows that if they are combined with the AC impedance measurement at high frequency the estimation accuracy will be further improved. Hence, in this paper a new approach to online AC impedance measurement at high frequency is proposed by paralleling a DC/DC converter with the PEM fuel cell stack. Then the mathematical model of the stack and the converter is developed and analyzed to verify the feasibility of this method. After that, the DC/DC converter is designed and an experiment is performed on a 30 kW stack of 120-serial cells. To calculate the impedance of a cell, the cell voltage monitor is used to simultaneously measure the output current of the stack and the voltage of each cell and this device is experimentally calibrated. Under pre-scheduled experiment conditions, the variation trend of the impedance at 320 Hz of two cells in serial as a unit validates the capability of AC impedance measurement at high frequency using the DC/DC converter.

Introduction

In the last two decades, the hydrogen fuel cell has experienced the growing attention from all over the world due to the increasing demand for clean energy with less carbon dioxide emissions. When compared with the conventional internal combustion engine, the by-product of the hydrogen fuel cell is just water if it continues working. Besides, the efficiency of the

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hydrogen fuel cell is not limited by the Carnot cycle and the system efficiency can reach 50% or higher [1]. With the development of technology, the volume specific power density and the mass specific power density has also been enhanced significantly by manufacturers like Toyota [2]. From the year 2014 on, the manufacturer Hyundai starts the lease for the hydrogen fuel cell vehicle in California [3] and in the late 2014 the manufacturer Toyota launched the mass production of the fuel cell vehicle [4].

Though much progress is made on the improvement of the performance of the fuel cell system, the durability and cost are still the largest obstacles that slow down its pace towards wide and fast commercialization [5]. Except for effects of material properties on the durability and cost, the integration of the fuel cell system is another dominant factor which should satisfy the demand for air supply, hydrogen supply, system cooling and start-up from below freezing point as well as the shut-down [6]. In these subsystems, the effect of the subsystem design on the water content and its distribution inside the fuel cell is the key problem which must be treated carefully because inappropriate water content may lead to flooding or drying and as a result the performance of the fuel cell is degraded. Just for example, the air supply subsystem needs to provide air with the appropriate relative humidity and flow rate, which makes sure that no flooding or drying happens inside flow channels of each fuel cell. Whether the external humidifier is needed in this subsystem influences the control of the relative humidity, system volume and start-up process greatly [7].

When integrating the fuel cell system, the water management strategy should be taken into consideration at the same time because this strategy depends on the accurate estimation or measurement of water content inside the fuel cell stack [8,9]. In order to acquire the water content inside the stack or even each fuel cell, the optional humidity sensor, the necessary pressure sensor and temperature sensor will be installed in the system. Feedback signals of these sensors are closely related to the water content and the real-time measurement results are the input variables of the management strategy. Before developing a proper strategy, the first thing to do which is also the most important is establish the model of the water content estimation only using measurable results. Many researchers have made efforts searching for ways to estimate the water content.

Mathematical models of water content estimation involving the gas diffusion layers, the membrane electrolyte assembly are described by many works. Amey et al. put forward a modified interpretation of the water activity presented by T.E. Springer in Ref. [10] and the modification directly affects the membrane water transport between the anode and the cathode in the presence of the liquid water inside the stack [11]. Then based on such modification a zero-dimensional isothermal model is calibrated to predict the flooding and drying conditions in the two electrodes observed at various current levels [12]. After that, they apply this model to study two cases of water management through modification of cathode inlet humidification and anode water removal.

Some studies are focused on mathematical models of the flow channels on either side. Jason et al. model and experimentally verify the evolution of liquid water and nitrogen fronts along the length of the anode channel with the fuel cell stack operated in the mode of a dead-ended anode [13]. Despite the fact that the accumulation of inert nitrogen and liquid water in the anode causes a voltage drop, it's recoverable by purging the anode. Hu et al. develop a fuel cell cathode model with separate inlet and outlet subsystems to incorporate the effect of flooding and oxygen starvation on the system dynamics and cell voltage [14]. By using the experiment data the proposed approach is validated and the designed control-oriented algorithm is applied to an online test system with good demonstration.

In Ref. [15], a three-dimensional model of polymer electrolyte fuel cells (PEFCs) is developed to investigate multiphase flows in fuel cells and their interactions. The results indicate that multiphase flows may exist in both anode and cathode diffusion media at low-humidity operation, and two-phase flow emerges near the outlet for co-flow configuration while is present in the middle of the fuel cell for counter-flow one. The dynamics of liquid water droplets in a single PEFC gas flow channel is investigated through theoretical and numerical analyses [16]. The expression for describing droplet shape change is derived, and it is found that the droplet can deform significantly at high gas-flow rates and when the droplet is relatively large. An approach is proposed of channel development for polymer electrolyte fuel cells PEFCs, i.e., to fill porous media in the channel region, allowing a simultaneous transport of gaseous reactant, liquid, heat, and electron through the porous-media channel [17].

Besides mathematical models, some advanced equipment is used in the study of the fuel cell. Chen et al. use the in-situ and non-destructive technique namely neutron radiography to visualize and measure the liquid water in a fuel cell at work [18]. The neutron radiography experiments are carried out at selected relative humidity and stoichiometry ratio of cathode inlet and results show that these parameters significantly influence current density distribution and water distribution. Based on work by Chen, Jason et al. extract the model parameters, such as the immobile saturation limit and the channel boundary conditions, and paradigms of the dead-end anode operation [19]. There is no denying that the work by Chen and Jason is very meaningful contributing to the understanding of the physical mechanism in a visible way. In fact, the neutron radiography needs such an expensive device that it is limited to be used only in the laboratory.

In addition, common sensors in the system are also meaningful for water content estimation. Rupak et al. perform the experiment to establish the relationship between the pressure drop multiplier and cell voltage at different operating conditions [20]. It is found that at a lower temperature a two-phase flow multiplier below 1.5 reduces flooding in the flow field while at a higher temperature the multiplier above 1.2 is preferred to maintain the hydration of the proton exchange membrane. Barbir et al. point out that an increase in the pressure drop, particularly on the cathode side of the fuel cell,

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