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Online humidification diagnosis of a PEMFC using a static DC–DC converter

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ABSTRACT

This paper deals with the online checking of the humidification of a Proton Exchange Membrane Fuel Cell (PEMFC). Indeed, drying or flooding can decrease the performance of the PEMFC and even lead to its destruction. An online humidification diagnosis can allow a real-time control. A good indicator of the membrane humidification state is its internal resistance. As known, the membrane ionic conductivity increases with the membrane water content. This resistance can be calculated at high frequency by dividing the voltage variation by the current variation. The proposed scheme makes use of measurements of current and voltage ripples coming from the association of a static DC–DC converter and the fuel cell. The experiment thus consists in computing the internal resistance in wet and dry conditions.

1. Introduction

The proton exchange membrane fuel cell (PEMFC) offers some advantages to other fuel cells as relative simplicity design and low operating temperature. An appropriate humidity condition not only can improve the performances and efficiency of the fuel cell [1], but can also prevent irreversible degradation of internal composition such as the catalyst or the membrane. Indeed, little or no water leads to membrane drying, which decreases the membrane ionic conductivity [2], and thus increases voltage drop across the membrane. Conversely, too much water causes flooding, the pores in the electrodes are filled with water and the transport of reactant gases to the catalyst site is thus obstructed. To have an adequate hydration of the PEM at each time, a real-time control of humidification state is needed. A good indicator of the humidification state is the membrane resistance [3,4].

This one can be measured by adding a high frequency component to the main fuel cell current. Indeed, it is well known that the "small signal" electrical behavior of a PEMFC can be represented, as in Fig. 1, by the Randles equivalent scheme [5].

This representation is a common and practical way of modeling an electrochemical cell. It consists of three resistors, r_m standing for ohmic resistance and r_a, r_c standing for anode and cathode charge transfert resistances, respectively, due to the hydrogen oxidation and oxygen reduction. $C_{dl,a}$ and $C_{dl,c}$ are the double-layer capacities at the electrode/membrane interfaces. Finally, $Z_{w,a}$ and $Z_{w,c}$ are the diffusion impedances associated to the gas diffusion in the anode and the cathode, respectively. At high frequency, this scheme can be reduced to the ohmic resistance r_m. Since the electronic and contact resistances contribution is negligible compared to the membrane resistance, the ohmic losses are often assumed to result in the membrane resistance. Therefore, this resistance

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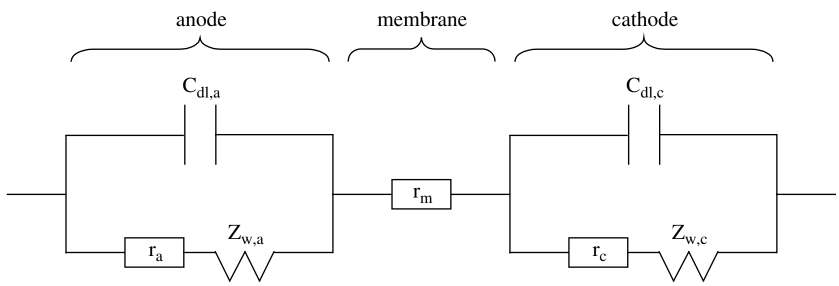

Fig. 1 – Equivalent circuit of an electrochemical cell.

can be deduced at high frequency, dividing the voltage variation by the current variation:

$$r_m = \left(\frac{\Delta v}{\Delta i}\right)_{HF} \quad (1)$$

Experimentally, frequency of the alternative current component, which enables r_m measurement, is chosen so that the phase shift between voltage and current is null [6].

In this paper, we present a measurement method for r_m that does not need any additional device for generating the high frequency current component. Indeed, as fuel cells are low voltage generators, it is most often necessary to use a power electronic converter, in order to increase fuel cell output voltage. The current ripple, naturally produced by this converter, enables r_m measurement if the switching frequency is high enough. We obtain that way a real-time control of the fuel cell humidification state [7]. Hence, in this lecture, we propose an additional use of the converter associated with the fuel cell. In the following parts, the test bench is described, then experimental results are detailed and discussed.

2. Fuel cell and converter unit

2.1. *Fuel cell experimental setup*

The considered stack is a 500 W proton exchange membrane fuel cell constituted of 23 cells, active area 100 cm^2. Fig. 2 presents a sketch of the experimental setup. As can be seen in this figure, air is supplied through a humidification unit to cathode, and pure dry hydrogen from cylinders to anode. The humidifier can be shut down by opening the solenoid valve v_1 so that dry air flows towards fuel cell cathode. This will be used to vary the humidification state of the fuel cell. A cooling system keeps the stack temperature constant. Data acquisition cards are used for all necessary control functions such as reference setting (gas flows, pressures, and stack temperature).

Fig. 3 shows the impedance spectrum of our 500 W PEMFC at 30 A, under a stack temperature of 55 °C and a humidifier temperature of 50 °C at atmospheric pressure. This experimentation was carried out by means of usual impedance spectroscopy method. The intersection with the real axis is obtained at 2 kHz, it gives the membrane resistance value, in this case $r_m = 40$ mΩ.

2.2. *Boost converter operating principle*

As it has been written before, fuel cells are low voltage generators, so that it is necessary to connect them to a converter [8]. The DC–DC power electronic converter used in the test bench [9,10] is a standard boost chopper. As depicted in Fig. 4, it is composed of an input inductor L, a power semiconductor switch denoted S, a diode D and an output capacitor C. State variables of this power electronic system are the input current i_{FC} and the DC link voltage v_{OUT}.

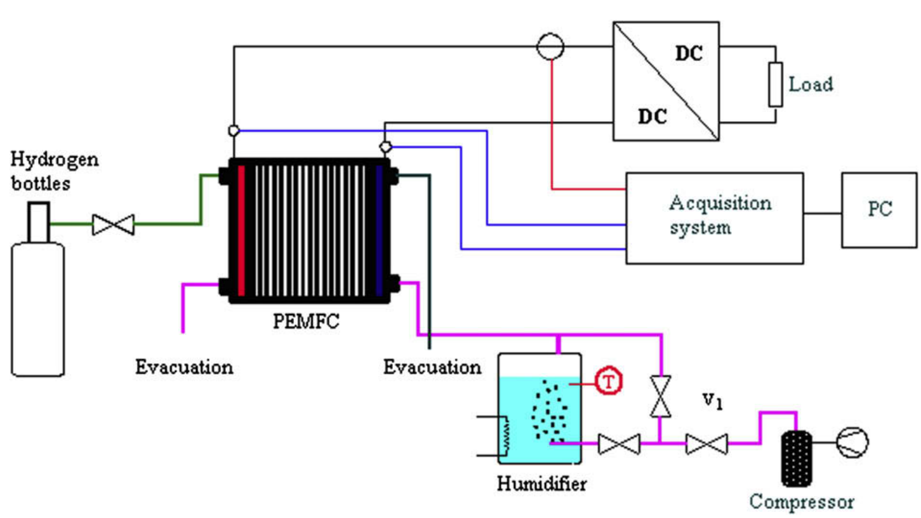

Fig. 2 – 500 W PEMFC (ZSW, Germany) connected to a DC–DC converter.