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Experimental analysis of a PEM fuel cell performance at variable load with anodic exhaust management optimization

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ABSTRACT

In this paper an investigation on the performance of a commercial Proton Exchange Membrane (PEM) fuel cell, installed at the laboratory of the University of Bologna, is carried out, taking into account the anodic exhaust management and its effects on the flooding phenomenon.

To address the problem of flooding, it is necessary to run periodically the purge process of the Fuel Fell (FC). Indeed, in this study the periodic anodic purge process in dead-end mode has been investigated. This operation is performed by opening a particular control valve, the Outlet Purge Valve (OPV), located along the anodic exhaust line.

The purge process has been analyzed at different FC power output levels. For each FC power level the optimized behavior of the FC operation was found, by regulating the time of flooding.

The aim of this analysis is to optimize the purge process to reduce the amount of hydrogen discharged with water, in order to increase the FC efficiency. An investigation on the benefits in terms of fuel utilization factor and costs, resulting from optimization of the FC purge process, is shown in the paper.

1. Introduction

Hydrogen and Fuel Cell (FC) technologies offer a pathway to enable the use of clean energy systems to reduce emissions, improve energy efficiency and stimulate the global economy [1,2]. Many studies on conventional combustion-based energy system show that improvements could be still achieved on the efficiency side, but with enormous efforts in terms of plant complexity (see for example a couple of our studies [3–7]) and still with CO_2 and other pollutants production. FCs have several benefits over conventional combustion-based technologies currently used in many power plants. Greenhouse gases and air pollutants responsible of smog and health problems are avoided at the point of operation of FC systems. On a life-cycle basis, if pure H_2 is used as a fuel, FCs emit only heat and water as byproducts [2].

Among FC technologies, Proton Exchange Membrane (PEM) FCs gained increasing attention especially for the large characteristic power density, low operating temperature but still with CHP potential (for example for residential applications [8,9]), and safe operation. Significant effort is being made towards producing PEM systems able to achieve the optimum balance of cost, efficiency, reliability and durability.

The short lifetime of PEM-FCs is a barrier to the deployment and commercialization of this power generation system. FC lifetime requirements vary significantly, ranging from 3000

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to 5000 operating hours for car applications, up to 40,000 operating hours for stationary applications [10–12]. Quantify the long-term performance and durability of an FC is currently still difficult. Indeed, all the mechanisms of FC components deterioration, affecting FC performance degradation, are not yet fully understood. The rate of degradation of the stack voltage is taken as a parameter indicative of the health status of an FC. Generally the range of voltage reduction rate is of 1–20 [μV/h] [11,12].

A phenomenon which particularly affects the longevity of a PEM-FC is the quality of water management. Inadequate water content, either globally within the stack or locally at certain locations within the unit cell, results in reduced conductivity in the membrane [13] and in any ions present in the catalyst layer. This results in increased ohmic losses and in a drop in cell voltage [10,12]. A balance must be realized between reactants (hydrogen and oxygen) delivery and water supply and removal [14]. St-Pierre et al. [15] showed that the life and longevity of an FC is strongly affected by the quality of water management in the PEM-FC. The management of water is critical for optimizing performance of a PEM-FC stack. In fact proper management of water within the cell ensures high efficiency, maintaining power density and stable operating conditions in the face of long periods of operation [16]. To this aim, it is necessary, on one hand, to keep the membrane humidified to have a high proton conductivity which is proportional to water content. On the other hand, an excessive accumulation of water (flooding) may negatively impact on the performance and lifetime of fuel cell.

In this paper an investigation on the flooding phenomenon of a commercial PEM-FC is carried out and a modification on the internal water management is implemented. The effects on FC performance are also analyzed. The investigation is based on the application and development of an experimental test bench.

2. The experimental test bench

The experimental test bench consists in a microgrid connecting several power sources and comprising in particular an FC system, designed to operate in island mode, but also connected to the external electric network (Fig. 1). The microgrid has been developed at the laboratory of the University of Bologna, as described more in detail in previous works by the authors [17–20]. Basically, this integrated energy system accommodates the following components:

- a PEM-FC stack, connected to a dedicated inverter;
- an electrochemical energy storage system (batteries) with a bidirectional inverter;
- a connection to external power sources;
- a load emulator subsystem;
- an electric board connecting the power sources inverters to the load emulator.

Fig. 1 shows the schematics of the electric microgrid where, in each branch, measuring sensors (indicated with S) and switch contactors allowing the opening or closing of branches, are installed.

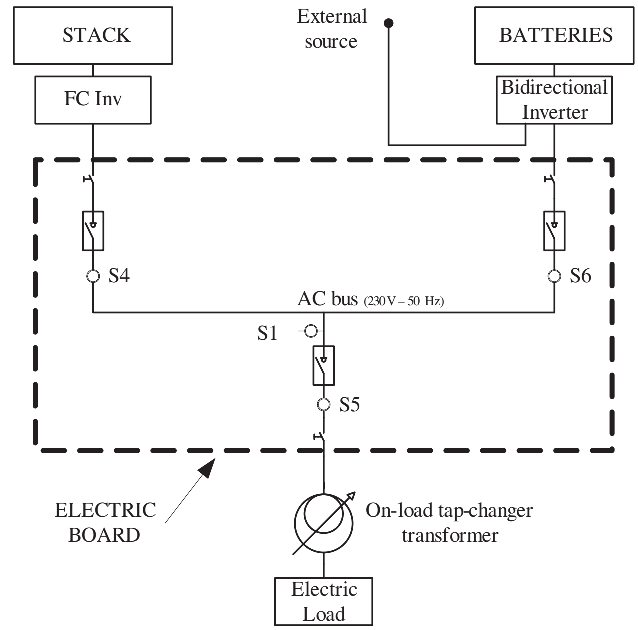

Fig. 1 – Experimental test bench.

The FC analyzed (Fig. 2), is a commercial H_2 fueled PEM-FC, rated for 4.5 kW of electric AC power, designed to operate at low temperatures (nearly 60 °C) at full load. The FC stack (Fig. 2b) is capable to provide 1–5 kW in DC, at voltage in the range 50–68 V and current intensity variable in the range 10–118 A [19].

In particular, Fig. 3 presents: (i) the supply circuits of fuel (in red); (ii) the air line (in light blue); (iii) the FC cooling system (in dark blue); and (iv) the stack and electric auxiliaries (in black). The FC cooling system comprises a tank of demineralized water, a pump (P), a heat exchanger (HX), where heat is transferred to an external CHP utilization circuit. In order to start-up the FC, a by-pass of the tank and a deviating valve DV is also positioned in the cooling circuit.

In the H_2 line, at the anode outlet side, the Outlet Purge Valve (OPV) is used, a valve operating in dead-end mode, i.e. accomplishing a periodic purging of the water (FC reaction product migrating in the anode compartment) and of the accumulating impurities.

The test bench is also endowed with a data acquisition system and the used sensors for current, voltage, temperature and mass flow rate are listed in Table 1. A real-time microcontroller, namely a National Instrument CompactRIO™ system [20,21], is used to acquire signals from sensors and to control the main input variables of the FC system and of the test bench (FC power set point, circuit breakers status). In order to simulate the external loads of different kind of users, a dedicated National Instrument control board is employed to generate different load scenarios.

3. The flooding phenomenon

Flooding is the accumulation of excess water which can occur at both the cathode and the anode side of the membrane [12].