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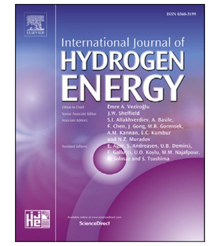

Analysis of proton exchange membrane fuel cells voltage drops for different operating parameters

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ABSTRACT

Fuel cells are devices that convert hydrogen into electric power using electrochemical reactions. It is an essential to understand the underlying dynamic behaviour of proton exchange membrane (PEM) fuel cells and optimize their performance. In this paper, the analysis of activation, ohmic and mass transport voltage drop is viewed. Different operating parameters such as the exchange current density, the transfer coefficient, electrolyte thickness, cell useful area and temperature effect on the voltage-current density curve are simulated. The results show that the voltage drops decrease the voltage and efficiency of the cell. Activation voltage drop reduces the voltage of about 0.2 V, ohmic voltage drop up to 0.8 V and mass transport to nearly to 1 V in high current densities. In addition, high pressures of hydrogen, oxygen and water lead to an increasing of the cell output power. Moreover, the temperature affects the performance of the cell that is reduced in low operating temperature conditions.

Introduction

The increasing energy demand will continue to grow in the coming years. A very large percentage of the energy required to meet this need comes from fossil fuels (oil, coal … etc). The use of these energy sources creates undesirable side effects, both locally (emissions) and globally (greenhouse gases effect). It now becomes necessary to reduce emissions of greenhouse gases (including CO2) to limit climate change. The search for alternative renewable energy sources is therefore a growing industry [1,2]. Not only because they are renewable sources, but it is also that they are not harmful to the environment [3,4].

In this context, hydrogen turns out to be a very strong contender, even if it is only an energy carrier and not a primary resource [5]. In addition, hydrogen can provide a response to climate issues to streamline the use of renewable energy by their scattered and random nature. Hydrogen, which does not exist in the natural state, can indeed be produced using electrolysis method. It is the process of using electricity to split water into hydrogen and oxygen. This electricity can be obtained from renewable energies sources [6]. These renewable energies represent some problems, especially in their non-linearity and stochastic behaviour; e.g. solar radiation and wind energy changes with random variation over the year. However, the hydrogen has not this disadvantage [7,8].

The fuel cell is needed so naturally as the missing link by converting chemical energy into electrical energy that can be manipulated with high yields. PEM fuel cells are electrochemical devices that directly convert the energy from the

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Nomenclature

$-\Delta\overline{g_f}$	the change of Gibbs free energy of the products and reactants
A	the constant of Tafel
B	a constant depends on the fuel cell operating state
E^0	electromotive force (EMF) at standard pressure
F	the Faraday constant (in C)
i	the current density (A/cm2)
i_0	the value that represents the beginning of the current density (from 0 to 0.05) A/cm2
i_{lim}	the limiting current density (A/cm2)
L	the thickness of the membrane (cm)
P	the pressure (in atm)
R	the gas constant (J/mol.K)
r	the membrane resistance (Ω)
R_c	proton resistance (Ω)
R_m	the equivalent resistance of the electrons (Ω)
T	the temperature (in K)
α	the charge transfer coefficient
∂_m	the specific membrane resistance (Ω.cm)

chemical reaction into electricity. They are used widely for appliance, vehicles and transportation because of their high power density, medical field and other sectors [9–11].

PEM fuel cell consists of an anode and cathode (electrodes) and an electrolyte membrane which is inserted between them. Generally, the theoretical open circuit voltage of a single fuel cell is around 1.2 V for a cell operating below 100 °C. However, this value is dropped to 0.7 V in real fuel cells. This voltage decrease is due to some losses that occurs in the fuel cells such as activation voltage drop, fuel crossover and internal currents, ohmic voltage drop and mass transport voltage drop [12]. Hence, a full analysis of these voltage drop is very important in the modelling of the fuel cell. They depend strongly on different parameters such as operating temperature, the pressure of reactants and the quantity of the produced water. That affects the electrodes and the performance of the cell. Several studies have tried to understand the dynamic of fuel cells [13]. In Ref. [14] a review of the main parameters influencing long-term performance and durability of PEM fuel cells is reached. In Ref. [15] a computational heat and mass transfer modelling in polymer-electrolyte-membrane (PEM) fuel cells models are discussed. In these references, only the effect of one parameter is studied. However, analysis of losses is also an important task that helps to understand this dynamics [16,17]. In Ref. [20] a steady-state Semi-empirical model of a PEMFC with variable condition is discussed; the modulization of the cell is taken using only empirical relation. In Ref. [21], global sensitivity analysis of proton exchange membrane fuel cell model is proposed; the authors attempt to plot the I-V curve using measured data from real fuel cell. However, they do not take into consideration the used parameters for the obtained results. In Ref. [22], some effects of operating parameters on the performance of proton exchange membrane fuel cells is illustrated. Here, only two parameters are taken into consideration, which does not give a complete information of the fuel cell losses. However, the analysis in these references does not take into consideration all the parameters affecting the fuel cell output voltage. Hence, in this paper, a full analysis of the activation, ohmic and mass transport voltage drops is studied using different operating parameters in the aim to increase the fuel cell efficiency.

The remaining part of this paper is organized as follows. In Section Fuel cell modelling, the modelling of Proton exchange membrane fuel cell principals is presented. In Section Fuel cell voltage drop, a theoretical background of fuel cell losses such as activation, ohmic and mass transport voltage drop is discussed. Section Simulation results presents the simulation results, the effect of different operating parameters on the performance of the fuel cell is discussed. The last section was devoted to the conclusion of the proposed work.

Fuel cell modelling

A fuel cell is an electrochemical device whose primary function is to convert chemical energy into electric power. The principle of the fuel cell process can be described as the inverse of the electrolysis of water. In fact, it is a controlled electrochemical combustion of hydrogen and oxygen, with simultaneous production of electricity, water and heat, according to an overall chemical reaction:

$$2H_2 + O_2 \rightarrow 2H_2O \tag{1}$$

Fig. 1 shows the working principle of PEM fuel cell, the main components are: two electrodes (anode and cathode) loaded with the catalyst (usually platinum), separated by an electrolyte, whose role is to allow the migration of ions from one electrode to the other, under the effect of the created electric field. The fuel constantly arrives at the anode and oxygen (usually supplied by air) continuously arrives to the cathode without coming into direct contact with each other.

At the anode, hydrogen is decomposed into positive and negative ions while at the cathode, oxygen is reduced (by absorbing electrons). For the system to return to its stable

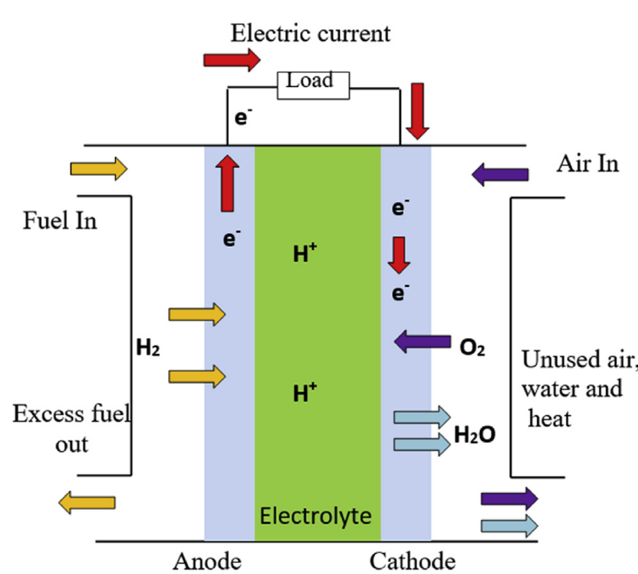

Fig. 1 – The working principle of PEM fuel cell.

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