Improvement in the Performance of Proton Exchange Membrane Fuel Cell with Effects of the Thickness and Conductivity of the Membrane

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Abstract. A theoretical model for analysis of proton exchange membrane (PEM) fuel cell is proposed. The membrane used in proton exchange membrane (PEM) fuel cell is of many different kind of materials. The Membrane has specific properties like proton conductivity, humidity and thickness which affect the performance of the PEM fuel cell. The proposed model is studied the effects of thickness and conductivity of membrane on the performance of the PEM fuel cell. The model has been validated with the experimental results trends and also the comparisons shows there is good agreement between the experimental data trends and the proposed model.

INTRODUCTION

A fuel cell is an electrochemical device that combines hydrogen and oxygen to produce electricity, with water and heat as its by-product. The proton exchange membrane fuel cell (PEMFC) converts chemical energy into electricity using an electrochemical cell, could be used as efficient power sources, offering high power density and low environmental impact. The study of nonlinear polarization curves and power of proton exchange membrane PEM fuel cell is presented. PEMFC are a type of fuel cell being developed for transport applications as well as for stationary fuel cell applications and portable fuel cell applications. Their distinguishing features include lower temperature/pressure ranges (50 to 100 °C) and a special polymer electrolyte membrane. PEMFCs operate on a similar principle to their younger sister technology PEM electrolysis. They are a leading candidate to replace the aging alkaline fuel cell technology, which was used in the space shuttle. PEMFCs are built out of membrane electrolyte assembly which includes the electrodes, electrolyte, catalyst, and gas diffusion layers. The pivotal part of the cell is the triple phase boundary (TPB) where the electrolyte, catalyst, and reactants mix and thus where the cell reactions actually occur. The membrane must not be electrically conductive so the half reactions do not mix. Operating temperatures above 100 °C are desired so the water byproduct becomes steam and water management becomes less critical in cell design. A majority of commercially available fuel cell systems today use Nafion, produced by DuPont. Nafion is a perfluorinated sulfonic acid polymer that is manufactured into a membrane. Although Nafion shows good conductivity (10^{-1}–10^{-1} S cm^{-1}) at temperatures less than 80^0C and high relative humidity (98% RH) and is the best PEM in these conditions, at high temperatures and low humidity, it does not work efficiently and its conductivity is reduced significantly. As a fuel cell membrane, Nafion has long been known to produce high power densities at low-temperature operation (< 100°C). One reason for the high power density is that, at low-temperatures (e.g. 80°C) and high relative humidity, Nafion conducts protons very efficiently, 75 mS/cm (Nafion 117) [1, 2]. Because of this, Nafion currently is the most common fuel cell electrolyte. However, due to the dependence of hydration for conductivity, Nafion is not designed for high-temperature (low relative humidity) operation [3]. At high relative humidity (high water activity), water is absorbed into hydrophilic regions of Nafion, which in turn conduct protons, necessary for generating the PEMFC reactions [4]. When the water required for proton conduction is eliminated from the system, membrane proton conductivity decreases rapidly [5].A basic schematic structure of PEMFC is used in our model as [6, 7].

THEORETICAL MATHEMATICAL MODEL

The proton exchange membrane (PEM) fuel cell converts chemical energy into electricity using an electrochemical cell, could be used as efficient power sources, offering high power density and low environmental impact. Determination of irreversible losses of a proton exchange membrane (PEM) fuel cell is considered to be extremely essential to assess its performance in terms of fuel cell voltage, limiting current density and power density. There are several sources that contribute to irreversible losses in a PEM fuel cell during the operation. These losses are often called overpotentials or polarizations that could be originated primarily from three sources namely activation overpotential, ohmic overpotential and concentration overpotential. Activation overpotential is associated mainly with the slowness of electrochemical reaction in the fuel cell. Ohmic overpotential is associated with the resistance of the membrane to the flow of migrating ions during an electrochemical process. The concentration overpotential occurs due to concentration gradients established as a result of rapid consumption of the reactant (oxygen) in the electrode during the electrochemical reaction.

The steady-state cell voltage is calculated by subtracting these catalytic and resistive losses from the reversible electrochemical cell voltage which can be calculated as following:

$V_{FC} = E^0 - V_{act.} - V_{conc.} - V_{ohmic}$ (1)

Using standard thermodynamic values of the entropy change, the open circuit voltage/reversible cell potential of a single cell (Nerst voltage) is used from the Ref. [8].

The activation losses can be expressed simply as the Tafel equation [9]:

$V_{act.} = a + b\ln(i)$ (2)

Where $a = -\frac{RT}{\alpha F}\ln(i_0)$ and $b = -\frac{RT}{\alpha F}$ (3)

The voltage drop by ohmic losses remains proportional to the current density drained from the cell:

$V_{ohmic} = iR_{ohmic}$ (4)

Ohmic overpotential depends on the electrical conductivity and thickness of every material that form the fuel cell as the bipolar plates, GDLs, CLs, MPLs and the membrane. Furthermore, the contact resistance between the GDL and the bipolar plate has been included in the ohmic overpotential due to the impact that it has over the performance of the PEM fuel cell [10]. The contact resistance has been estimated according to a well defined technique [11]. The expression to calculate the ohmic overpotential is shown in [12, 17].

$$V_{ohmic} = i\left(2\frac{t_{BP}}{\sigma_{BP}} + 2\frac{t_g}{\sigma_g} + 2\frac{t_c}{\sigma_c} + 2\frac{t_{MPL}}{\sigma_{MPL}} + \frac{t_m}{\sigma_m} + 2R_{contact}\right) \quad (5)$$

Where t_i and σ_i represent the thickness and the electrical conductivity of the BPL (bipolar plate), bipolar plate (BP), gas diffusion layer (g), micro porous layer (MPL) and catalyst layer (c), membrane (m) and $R_{contact}$ represents the contact resistance between the GDL and the bipolar plate .The electrical conductivity of the BP, GDLs, MPLs and CLs was obtained from the technical datasheet of each material [13 to 15]. However, the membrane proton conductivity (Nafion 117) depends strongly on the water content inside the membrane. Therefore, depending on the cell operating conditions, the membrane protonic conductivity will be different. The expression to calculate the membrane protonic conductivity as a function of the water content is shown below. The expression is widely used in PEM fuel cell models and it was developed by Springer [16].

$$\sigma_m = (0.005193\lambda_m - 0.00326)\exp[1268\left(\frac{1}{303} - \frac{1}{T}\right)] \quad (6)$$

Where λ_m is the water content inside the membrane and T is the operating temperature (K). The parameters can vary for different membranes, but the general behavior of the model was verified in different operating conditions.

An empirical equation better describes the concentration loses [18, 20]:-

$V_{conc} = mexp(n-1)$ (7)

Where m and n are empirical coefficients with typical values close to 3 x10^{-5} V and 8 cm^2/A, respectively[19].

Our new model is by substituting the eqs.(2,5,7) into eq.(1) , we have substituted the experimental values as described in references above and [21,22].

RESULTS AND DISCUSIIONS

According our model the performance of PEMFC is mainly depends upon the thickness and conductivity of the membrane.

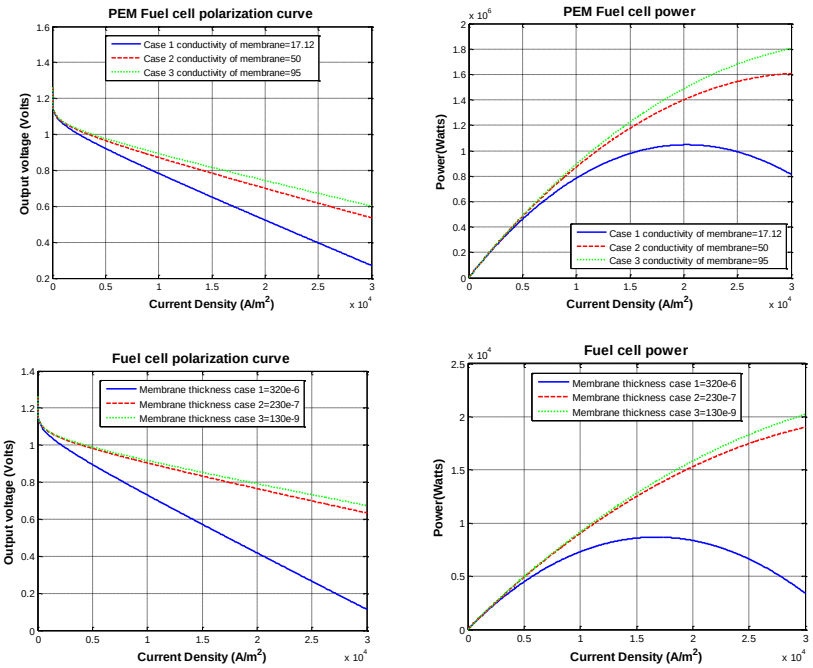

FIGURE1: Upper two curves shows effect of membrane thickness and lower two shows conductivity effect.

In our model we assumes theoretical values for membrane thickness and conductivity and other experimental values as described in references above and [21,22]. The effects show that the performance of PEMFC improves if membrane thickness is scaling down and by improving the conductivity of the membrane. Hence it's a challenge for experimentalists to investigate the type of materials and their existence at micro, nano level. The model has been validated with the experimental results trends and comparisons shows there is good agreement between the experimental data trends and the proposed model.

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