Analysis of Effective Parameters of a PEMFC Considering Optimal Operation

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Abstract: Fuel Cell (FC) is electrochemical systems capable to convert the oxygen and hydrogen chemical energy to electrical energy. FC is as a promising alternative due its suitable efficiency, low pollution to the environment, high reliability and durability and excellent dynamic response. In this study we have implemented simple PEMFC in GAMS environment considering its input hydrogen molar flow rate consumption. Then the impact of effective operational parameters is investigated on optimal operation and output power of PEMFC. This study can ensure PEMFC optimal operation and maximizing its generated power considering obtained results from modeling and different effects of each operational parameter.

Keywords: Fuel Cell (FC), GAMS, modeling, optimal operation, Proton Exchange Membrane (PEM)

INTRODUCTION

FC is electrochemical systems capable to convert the chemical energy of oxygen and hydrogen to electrical energy during which some heat and water is generated as well. The use of FC based on power generation is expected to become more widespread in future due to better power quality, reliability, portability and ecological constraints. These characteristics and the possibility of refueling the cell with different fuels are increasing the interest or the applications as electric power sources. The commonly available FC includes polymer membrane, alkaline, phosphoric acid, molten carbonate and solid oxide based FCs. Due to its low operating temperature and fast start up characteristic, the PEMFC is most attractive for residential use among the various types of FC (Chiu et al., 2004).

A FC based on power system consists of a reformer, FC stack and power conditioner, able to adapt the operating conditions to the requirements of the load. FC generates DC power, normally (Pathapati et al., 2005).

In many literature is developed PEMFC measuring and control system but they didn’t focus on measuring sensors and evaluation the operational parameters impact on PEMFC generated power considering consumption of hydrogen molar flow rate. In this study a PEMFC 500-W BCS stack is modeled in GAMS environment. Then in sensitivity analysis is investigated cell operational parameters impact on PEMC output power versus hydrogen molar flow rate consumption and the effective parameters on PEMFC optimal operation are determined. The aim of this sensitivity analysis is to find the effective parameters for better control, improvement the optimal output power generation and higher efficiency of a PEMFC.

PEMFC MODELING

FC converts oxygen and hydrogen chemical energy to electrical energy during which some heat and water is generated as well. Typical scheme of FC system and equivalent electrical circuit model shown in Fig. 1-2 (Friede et al., 2004).

The output voltage in each cell is little, so some cells connected in series to gain a bigger output voltage and that is called FC stack. The operation of FC is described by polarization curve and in a constant state which shows FC voltage based on the current (Buasri and Salameh, 2006).

The basic areas which affect the overall polarization are Ohmic, activation and Concentration Polarization (Dongjing and Li, 2007).

PEMFC voltage: According to polarization curve, FC voltage can be defined by:

\[
V_{FC} = E_{\text{ernst}} - V_{\text{act}} - V_{\text{ohmic}} - V_{\text{con}}
\]

(1)

The thermodynamic potential of the FC that represents its reversible voltage can be calculated by:
**Ohmic polarization:** Ohmic voltage drop occurs due to resistive losses in the FC and can be obtained as follows:

\[
E_{\text{ohm}} = i_{\text{FC}} \left( R_M + R_C \right)
\]  
(3)

where, \(i_{\text{FC}}\) refers to FC current. \(R_C\) represents resistance of FC electrodes against movement of electrons and \(R_M\) is resistance of FC membrane against ions passing, which can be expressed by:

\[
R_M = \rho_M \left( l / A \right)
\]
(4)

where, \(\rho_M\) represents cell membrane specific resistivity (\(\Omega\).m), \(A\) is cell active area (cm²) and \(l\) is membrane thickness (cm).

**Activation polarization:** Activation voltage drop occurs due to slow reactions on the surface of electrodes which calculated by:

\[
V_{\text{act}} = - \left[ \xi_1 + \xi_2 T + \xi_3 T \ln(C_{O_2}) + \xi_4 T \ln(I_{FC}) \right]
\]
(6)

where, \(C_{O_2}\) refers to oxygen concentration rate on the catalyst surface which can be defined as follow:

\[
C_{O_2} = \frac{P_{O_2}}{5.08 \times 10^6 \exp\left(-\frac{498}{T}\right)}
\]
(7)
Concentration polarization: Concentration voltage drop occurs due to reduction in density of reaction materials which is called mass transport losses and can be calculated by:

$$V_{con} = -B \ln(1 - (J/J_{max}))$$  

(8)

where, Jmax represents maximum current density in FC.

According to all voltage drops in FC, for n cells forming a stack, output power of FC stack is calculated as follows:

$$P_{FC} = N_{FC} \cdot V_{FC} \cdot I_{FC}$$  

(9)

where, NFC is the number of cells in series.

PEMF current: The current of FC can be described as a linear function of hydrogen flow rate to FC and can be calculated as follow (El-Sharkh et al., 2004):

$$I_{FC} = \left(\frac{2F}{N_{FC}}\right)\left(\frac{W_{H_2}}{M_{H_2}}\right)$$  

(10)

In this study the profile of hydrogen molar flow rate variation for PEMFC consumption is considered during a fully day as Fig. 3.

Static behavior of PEMFC is modeled using Eq. (1) to (10). Based on PEMFC electrical circuit model, its mathematical modeling is established in GAMS environment to describe the types of voltage drops and PEMFC output voltage corresponding PEMFC hydrogen molar flow rate consumption.

In this study a 500W BCS stack is applied and the base parameters are presented in Table 1 (Jeferson et al., 2006).

Considering PEMFC electrical circuit model and its mathematical modeling in GAMS environment, all polarization voltage and output voltage obtained from modeling shown as Fig. 4.

According Fig. 4, it is clear that PEMFC output voltage decrease in the beginning and ending with comparatively great drop.

The curves of PEMFC output voltage and output power density as a function cell's molar flow rate consumption obtained for base parameters as Fig. 5-6.
SENSITIVITY ANALYSIS

In this section the impact of PEMFC operational parameters like temperature, pressure, membrane humidity and cell active area (Correa et al., 2005) investigated on polarization curve, output power and its optimal operation. The obtained results depicted in Fig. 7-8. According to Fig. 7-8, we can say that increase (decrease) of FC’s operational temperature and hydrogen partial pressure will cause increase (decrease) in FC output voltage and power (FC polarization curves). The reason of increase due to operational temperature is that higher temperatures improve mass transfer within the FC and results in a net decrease in cell. Also, reason of increase due to hydrogen partial pressure is that hydrogen partial pressure increase will improve the mass transfer of hydrogen in the cathode and hence increase the power output of FC.

Table 1: Typical FC parameter of 500W BCS stack

<table>
<thead>
<tr>
<th>Typical FC parameters of 500W BCS stack</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cells in FC stack (NFC)</td>
<td>32</td>
</tr>
<tr>
<td>Cell active area (A)</td>
<td>64 cm²</td>
</tr>
<tr>
<td>Maximal current density (Jmax)</td>
<td>469 mA/cm²</td>
</tr>
<tr>
<td>Operation temperature (T)</td>
<td>333 K</td>
</tr>
<tr>
<td>Membrane thickness (l)</td>
<td>178 μm</td>
</tr>
<tr>
<td>Partial pressure of hydrogen (P(H₂))</td>
<td>1 atm</td>
</tr>
<tr>
<td>Partial pressure of oxygen (P(O₂))</td>
<td>0.2095 atm</td>
</tr>
<tr>
<td>Equivalent resistance to proton conduction (RC)</td>
<td>0.0003 Ω</td>
</tr>
<tr>
<td>Parameter corresponding to Vact (ξ₁)</td>
<td>-0.948</td>
</tr>
<tr>
<td>Parameter corresponding to Vact (ξ₂)</td>
<td>0.002286+0.0002 ln (A)+0.000043 ln (CH₂)</td>
</tr>
<tr>
<td>Parameter corresponding to Vact (ξ₃)</td>
<td>0.000076</td>
</tr>
<tr>
<td>Parameter corresponding to Vact (ξ₄)</td>
<td>-0.000193</td>
</tr>
<tr>
<td>Membrane humidity (φ)</td>
<td>23</td>
</tr>
<tr>
<td>B</td>
<td>0.016 V</td>
</tr>
<tr>
<td>Faraday’s constant (F)</td>
<td>96 484 600 C/kmol</td>
</tr>
<tr>
<td>Universal gas constant (R)</td>
<td>8314.47 J/(kmol·K)</td>
</tr>
</tbody>
</table>
Table 2: The impact of FC operational parameters variation on its output power

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Operational Temperature (OT) (%)</th>
<th>Partial Pressure (PP) (%)</th>
<th>Membrane Humidity (MH) (%)</th>
<th>Cell Active Area (CAA) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1% increase</td>
<td>0.96</td>
<td>0.327</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1% decrease</td>
<td>1.325</td>
<td>0.365</td>
<td>0.214</td>
<td>0.617</td>
</tr>
</tbody>
</table>

cell voltage in this study corresponding to hydrogen molar flow rate consumption.

CONCLUSION

This study presents the electrochemical model of PEMFC and establishes the GAMS mathematical modeling based on it. Detailed researches on polarization curves have been carried through to boost FC performances. Impact of FC parameters investigated on its output power and optimal operation. Some parameters which is not so accurate in some papers but very important are pointed out. We have found that temperature has significant impact on PEMFC’s characteristics whereas impact of partial pressures, membrane humidity and cell active area is lower. Based on the obtained results, we can define design criteria for measurement and control equipment in FC systems with different complexity to ensure optimal operation with optimal output power and output voltage.

REFERENCES


