DETERMINATION OF AN OPTIMUM PERFORMANCE OF A PEM FUEL CELL BASED ON ITS LIMITING CURRENT DENSITY

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Introduction
There are several sources that could contribute to the irreversible losses in a fuel cell during the operation. These losses are called overpotentials or polarizations and originated primarily from three sources namely activation polarization, ohmic polarization and concentration polarization. In the past decades, several studies were conducted on modelling the polarization curve with simple mathematical equations [1]. In addition, several parametric equations were set up at various operating conditions of a fuel cell such as temperature and pressure. Conversely, Kazim [2] set up mathematical criteria that predicted a minimum PEM fuel cell efficiency point where beyond that point the fuel cell could operate and the annual fuel cost and electricity cost are economically feasible.
The objective of the current study is to determine optimum current density and fuel cell voltage with its related overpotentials that a PEM fuel cell could operate based on its limiting current density. The optimum values will be calculated by relating the activation overpotential in the standard cell voltage equation with the concentration overpotential.

Fundamental Equations
Voltage of the fuel cell V_{FC}, can be determined through the following standard general equation [3]:

$$V_{FC} = V_{oc} - \eta_{act} - \eta_{con} - \eta_{ohm} \qquad (1)$$

where, V_{oc}, η_{act}, η_{con}, η_{ohm} are open–circuit voltage, activation overpotential, concentration overpotential and ohmic overpotential, respectively. In the current study, the open-circuit voltage is taken to be a constant value of 1.1V [4].

$$V_{FC} = V_{oc} - \left\{\frac{\Re T}{\alpha n F}\ln\left(\frac{i}{i_o}\right)\right\} - \left\{\frac{\Re T}{nF}\ln\left(1-\frac{i}{i_L}\right)\right\} - i\,R \qquad (2)$$

$$V_{FC} = V_{oc} - A\ln(K\varepsilon) - B\ln(1-\varepsilon) - \varepsilon\, i_L\, R \qquad (3)$$

Results and discussion
Calculations of i/i_L, optimum operating current density, i and optimum cell voltage V_{opt} were carried out at limiting current density from i_L=0.5 A/cm^2 to 1.5 A/cm^2, ohmic resistance of R=0.10 $\Omega \cdot cm^2$ and R=0.20 $\Omega \cdot cm^2$ and factor K from 10^3 to 10^5 presented in tables 1-3. Optimum values of current density, overpotentials and cell voltage are calculated at overpotential coefficients A and B of 0.05 V and ohmic resistance of R=0.10 $\Omega \cdot cm^2$ and presented in table 1, which represent a base case. It is observed that drastic increase in the optimum current density and cell overpotentials occur when the fuel cell limiting current density is increased. For instance, the optimum fuel cell operating current density increases from 0.31 A/cm^2 at i_L=0.5 A/ cm^2 to 1.15 A/ cm^2 at i_L =1.5 A/ cm^2. Conversely, the optimum cell voltage decreases with increasing the optimum current density deduced from equation (3), where an increase in activation and concentration overpotentials takes place in addition to a more prominent change in the ohmic overpotential.
Without any doubt, the activation overpotential η_{act}, at coefficient A greater than B would be greater than the concentration overpotential η_{con} as depicted in table 2. The ohmic resistance R is the same as in the base case of R=0.10 $\Omega \cdot cm^2$. A general observation made can be made about this case is that the optimum current density, concentration overpotential, activation overpotential and ohmic overpotential in this case, are at least 5% greater than the base case where A=B. This is mainly due to a higher coefficient (i.e. A) in the second order equation leading the results to be slightly higher than the base case. Among all the parameters η_{act} is increased most mainly due to 50% increase in it coefficient A. Again, the an optimum cell voltage decreases with increase in coefficient A due to increase in the operating current density and cell overpotentials.

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A similar observation can be made regarding the above parameters in case if the ohmic resistance is doubled to R=0.20 $\Omega \cdot cm^2$, as presented in table 3. Among all the parameters, a two-fold increase in the ohmic overpotential is noticed since it is a linear function of the fuel cell's membrane ohmic resistance, whose value is doubled.

Conclusion

In this paper, a study on the determination of an optimum current density and a cell voltage that a PEM fuel cell should operate based on its limiting current density i_L was conducted. The conclusions are summarized as follows:

- Higher overpotentials and optimum current densities are achieved with an increase in the limiting current density i_L. Conversely, a decrease in the optimum cell voltage can be detected with increasing i_L.
- Higher activation overpotential and optimum cell voltage can be achieved with an increase in the factor K.
- Higher overpotentials, optimum current densities are achieved with increase in the ohmic resistance R. On the other hand, a slight decrease in the optimum cell voltage can be detected with increasing R.
- Higher overpotentials, optimum current densities are achieved with increase in any or combination of coefficients A and B. On the other hand, a decrease in the optimum cell voltage can be detected with increasing the any or both coefficients.
- Values of coefficients A and B and ranges of the factor K used in the study, were considered to be typical for determination of a fuel cell voltage.
- The analysis is valid over wide ranges of possibilities through interpolation and extrapolations.

References

[1] Kim J, Seong L, Srinivasan S, Modeling of Proton Exchange Membrane Fuel Cell Performance with an Empirical Equation, J Electrochem Soc, 1995;142: 2670-2674.

[2] Kazim A. A novel approach on the determination of the minimal operating efficiency of a PEM fuel cell. Renewable Energy, 2002; 26 (3): 479-488.

[3] Kinoshita K, McLarnon F. and Cairns E. Fuel Cells a Handbook. U.S. Department of Energy, 1988.

[4] Kazim A, Liu H and Forges P, Modeling of Performance of PEM Fuel Cells with Conventional and Interdigitated Flow Fields, J Applied Electrochem, 1999; 29: 1409-1416.

Table 1: Optimum values of a PEM fuel cell operating current density, cell overpotentials and cell voltage at A=B=0.05V and R= 0.10 ohm. cm^2.

i_L (A/cm^2)	Current Density, i_{opt} (A/cm^2)	η_{act} (V) **Fuel Cell Voltage, V_{opt} (V)**		
		K= 10^3	**K= 10^4**	**K= 10^5**
0.5	0.31	0.321 **0.796**	0.436 **0.681**	0.552 **0.566**
0.75	0.5	0.325 **0.780**	0.440 **0.665**	0.555 **0.550**
1.0	0.71	0.328 **0.763**	0.443 **0.648**	0.558 **0.532**
1.25	0.92	0.330 **0.744**	0.445 **0.629**	0.560 **0.514**
1.5	1.15	0.332 **0.726**	0.447 **0.610**	0.562 **0.495**

Table 2: Optimum values of a PEM fuel cell operating current density, cell overpotentials and cell voltage at A= 1.5B= 0.075V and R= 0.10 ohm. cm^2.

i_L (A/cm^2)	Current Density, i_{opt} (A/cm^2)	η_{act} (V) **Fuel Cell Voltage, V_{opt} (V)**		
		K= 10^3	**K= 10^4**	**K= 10^5**
0.5	0.34	0.490 **0.634**	0.662 **0.461**	0.835 **0.288**
0.75	0.54	0.494 **0.616**	0.666 **0.443**	0.839 **0.271**
1.0	0.75	0.496 **0.598**	0.669 **0.425**	0.842 **0.252**
1.25	0.97	0.499 **0.579**	0.672 **0.406**	0.844 **0.233**
1.5	1.20	0.501 **0.559**	0.674 **0.386**	0.846 **0.214**

Table 3: Optimum values of a PEM fuel cell operating current density, cell overpotentials and cell voltage at A=B= 0.05V and R= 0.20 ohm. cm^2.

i_L (A/cm^2)	Current Density, i_{opt} (A/cm^2)	η_{act} (V) **Fuel Cell Voltage, V_{opt} (V)**		
		K= 10^3	**K= 10^4**	**K= 10^5**
0.5	0.35	0.328 **0.763**	0.443 **0.647**	0.558 **0.532**
0.75	0.58	0.332 **0.726**	0.447 **0.610**	0.562 **0.495**
1.0	0.81	0.335 **0.686**	0.450 **0.571**	0.565 **0.456**
1.25	1.05	0.337 **0.645**	0.452 **0.530**	0.567 **0.415**
1.5	1.29	0.338 **0.602**	0.453 **0.487**	0.568 **0.372**