Sensitivity analysis of impedance characteristics of a Laminar flow-based fuel cell

S.M. Rezaei Niya, P.D. Barry, M. Hoorfar
University of British Columbia, School of Engineering, V1V 1V7, BC, Canada

An air-breathing laminar flow-based fuel cell (LFFC) is a small-scale power source introduced recently. The phenomenon of laminar flow allows liquid fuel and oxidant to flow side by side without mixing, yet maintaining ionic conductivity [1]. The electrochemical impedance spectroscopy (EIS) technique, which estimated the impedance of the system by perturbing the potential (or current) and measuring the current (or potential) [2], was employed to study these fuel cells [e.g., 3] beside other numerical models [e.g., 4].

In this research, the EIS technique is employed to measure the sensitivity of LFFC to fuel concentration, and the potential and current changes. The impedance of the cell is measured in the frequency range of 1 kHz – 10 mHz with 10 points/decade in various fuel concentrations (i.e., 0.8 M, 1 M and 1.2 M) and potentials (i.e., 0.05 V, 0.15 V, 0.25 V and 0.4 V for which the corresponding currents are 10.8 mA, 6.6 mA, 4.0 mA and 3.5 mA, respectively). Each measurement has been repeated 3 times and the average Nyquist plots are shown in Figure 1. The Nyquist plots are then divided into the high frequency (1 kHz – 10 Hz), the moderate frequency (10 Hz – 0.1 Hz) and the low frequency (0.1 Hz – 10 mHz) regions, and each region is modeled by the equivalent circuit presented in Figure 2. For low frequency region, an inductance is also paralleled with resistance (R) to be able to capture the inductive loops appeared in some cases (e.g., see the curve of 1.2 M presented in Figure 1) in the low frequency region. Also, in order to have the same degree of freedom, the constant phase element (CPE) is replaced by a capacitance (C).

The values of R_0, R, Q (i.e., coefficient of the CPE element), and n (i.e., the power of CPE) for the high frequency region; R, Q, and n for the moderate frequency region; and R, C, and L for the low frequency region and their standard deviations are determined. Using the t-test method, these values are compared in the successive measured potentials and fuel concentrations to identify those that are statistically different. The t-test results show that although some of the elements values are not statistically different in successive points (e.g. R_0 and R in the high frequency region for 0.15 V and 0.25 V, and Q and n in the moderate frequency region for 0.8 M and 1 M), there is always at least one element which is different, resulting the Nyquist plots that are statistically different in successive potentials or fuel concentrations. Based on the above method, the statistically indifference interval is determined as an interval that the parameters of interest (i.e., the fuel concentration and potential in this study) can be changed without any statistically detectable change in the target (i.e., the Nyquist plot in this study) [5]. To find this range, the largest change in the parameter failing the t-test is determined. If the t-test is passed even for one of the equivalent circuit element values it can be concluded that the Nyquist plots are statistically different, and hence the fuel concentration or the potential change has been detected.

Using the method described above, the elements with the largest t-test values (i.e., R in the moderate frequency range for the potential changes, and n in the high frequency range for the fuel concentration changes) are studied. Assuming linear interpolation for element values and their standard deviations between successive points, the potential and fuel concentration indifference intervals can be determined [5]. As the current is also measured at each potential, the same sensitivity study is repeated for the current. The results are shown in Table 1. These results can also be employed to find the required precision in impedance measurements.

References

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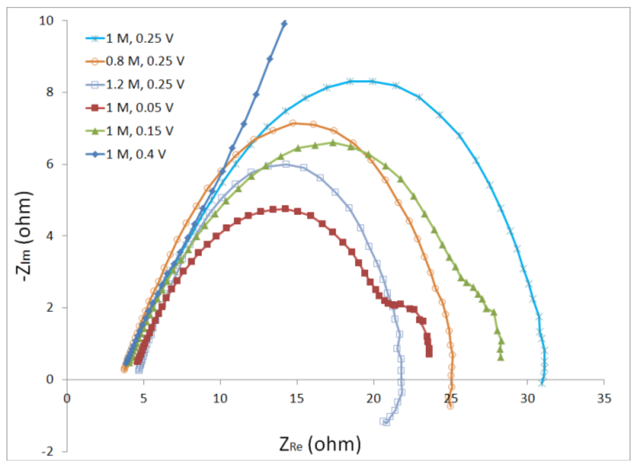

Figure 1: The measured Nyquist plots of a laminar flow-based fuel cell (LFFC)

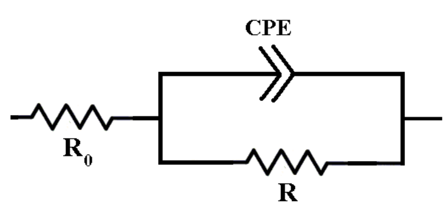

Figure 2: Equivalent circuit used for the high and moderate frequency regions

Table 1: Indifference interval for various potential, current and fuel concentration ranges

Ranges	Minimum Detectable Changes
0.05-0.15 V	0.00980 V
0.15-0.25 V	0.000945 V
0.25-0.4 V	0.00614 V
10.8-6.6 mA	0.412 mA
6.6-4 mA	0.0246 mA
4-3.5 mA	0.0205 mA
0.8-1 M	0.0164 M
1-1.2 M	0.0185 M